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ANAEROBIC TREATMENT
OF
SYNTHETIC ORGANIC WASTES

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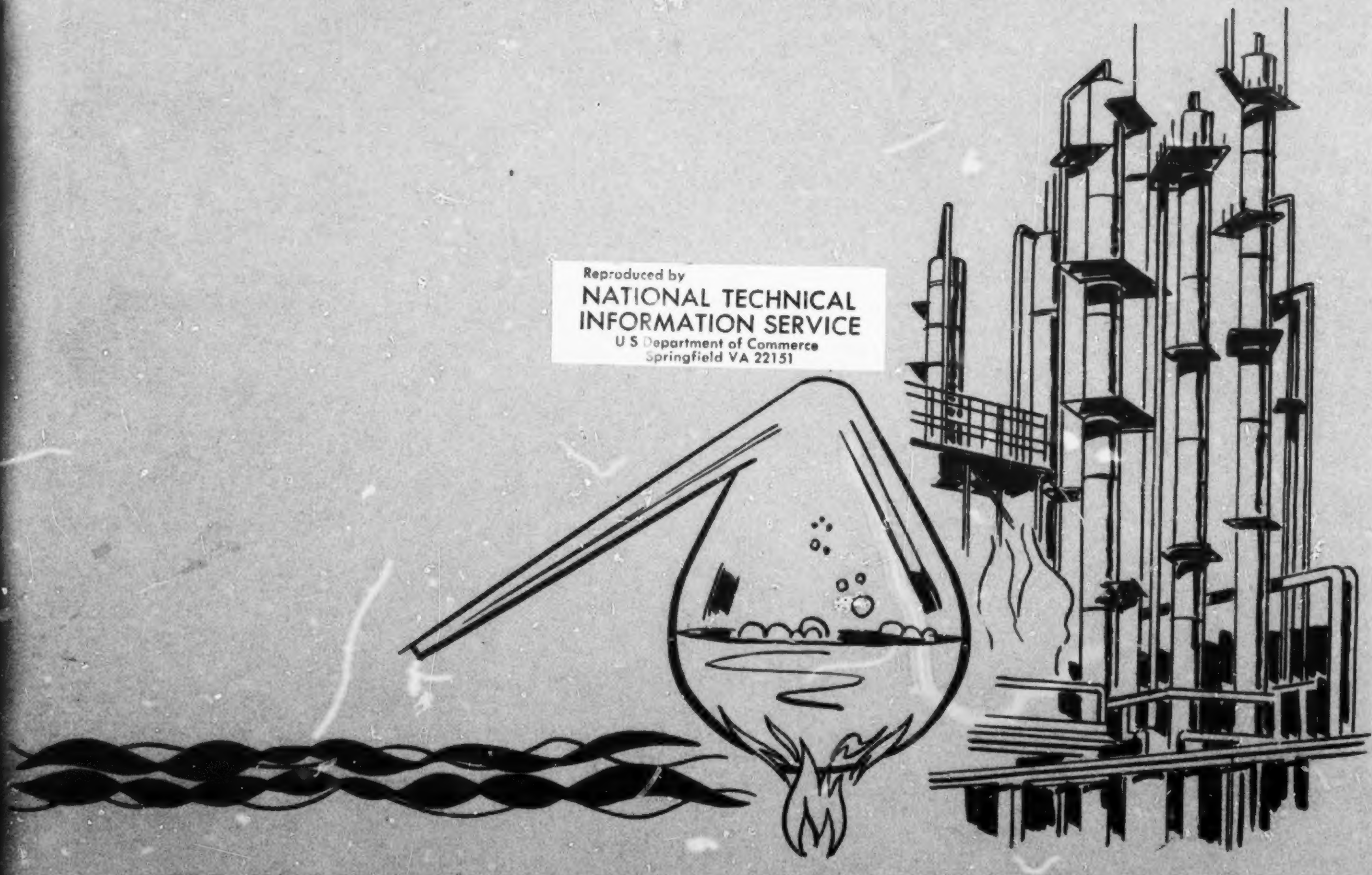

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ANAEROBIC TREATMENT OF SYNTHETIC ORGANIC WASTES

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ABSTRACT

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SECTION I

CONCLUSIONS

1. In warm, spacious locations anaerobic lagooning has been shown as an effective, economical process for pretreating petrochemical wastes prior to aerobic stabilization in a 30 gpm pilot plant operated over a period of 11 months.

2. Anaerobic lagoon effluent fed to an aerated stabilization-facultative lagoon process was treatable; a final effluent suitable for release to the environment was produced. A dissolved oxygen residual of 1.5 mg/l was found to be necessary in the aerated stabilization process.

3. The performance of anaerobic lagoons in organic removal was dependent upon both the volumetric loading rate (lb organic/unit volume-unit time) and the lagoon temperature.

4. Lagoon performance decreased markedly at temperatures above approximately 43°C and below 20°C.

5. Photosynthetic bacteria found to exist in the anaerobic lagoon could effectively oxidize anaerobically produced sulfides. These bacteria also could utilize volatile acids, but then exhibited a lower rate of sulfide oxidation. The lagoon process was unique among the three alternatives in its tolerance of sulfates in the feed.

6. Surface sulfide concentration was found to be dependent upon lagoon depth, while BOD removal efficiency was only slightly dependent upon depth.

7. All influent volatile organic compounds identified chromatographically were at least partially removed in the anaerobic lagooning process with the exception of produced intermediates such as volatile acids. No chromatographically identifiable materials were found in the effluent from the series system.

8. The increase in performance of anaerobic lagoons with decreased volumetric loading was found to be due to greater removal of all identified influent constituents rather than increased removal of any one.

9. The anaerobic-lagoon/aerated-stabilization/facultative-lagoon process was found to have both performance and economic advantages over a completely mixed activated sludge system.

10. A design procedure was developed to apply the anaerobic pretreatment process in a variety of situations.

11. Eleven-month operation of a large-scale pilot plant provided greater than 90 percent removal on a total-BOD_5 basis and 95 percent removal on a soluble-BOD_5 basis.

12. The pilot plant was extremely stable with respect to pH and organic shock loadings.

13. Degradation of biosolids in the facultative lagoons was found to be 56 percent on a total suspended solids basis and 70 percent on a volatile suspended solids basis.

14. Anaerobic filters and contact digesters provided satisfactory removals when treating dilute wastes in bench-scale studies. Neither unit provided satisfactory removals when tested on a semi-pilot scale with actual wastes.

15. The semi-pilot scale contact digester and anaerobic filter both provided conversion of complex organics to volatile acid intermediates at levels comparable to the anaerobic lagoons which were more efficient in removal of oxygen demand. The difference in performance between the lagoon and filters and contact digesters was due to the ability of the lagoons to metabolize produced volatile acids.

16. The anaerobic lagoon process was found to have the best performance and the least cost of the three anaerobic alternatives considered (anaerobic lagoon, anaerobic contact-digester, and submerged filter processes).

17. A series anaerobic/aerated-stabilization/facultative-lagoon system was estimated to cost $0.034 per pound of BOD_5 removed for a 10 mgd plant treating an 800 mg/l BOD_5 waste. The annual cost was approximately 25 percent investment and 75 percent operating costs.

SECTION II

RECOMMENDATIONS

1. In order to apply the anaerobic process on a wider basis it would be necessary to

   a) Increase the allowable loadings in the anaerobic lagoon process, and/or

   b) Determine the cause and a remedy for problems encountered with methane generation in the packed column and contact digestion processes.

   c) Investigate the performance of anaerobic lagoons having liquid depth in excess of 12 feet.

   d) Investigate the performance of anaerobic lagoons in locations having colder climates than the project site.

The digester or filter process conceivably could be used as is for a pretreatment approach in specialized locations with streams difficult to treat anaerobically by utilizing their ability to convert complex materials to more readily degradable intermediates. The loading to the anaerobic lagoon system conceivably could be increased by determining the limiting step in the metabolic processes within the system.

2. The study of organic compounds of low volatility which are not easily identified (via gas-liquid chromatography) also is needed to determine whether these materials can be removed by the anaerobic process. An example would be heavy organics causing taste-and-odor problems in water supplies.

3. The value of the anaerobic processes could rest in properties other than oxygen demand removal. Studies on difficult-to-degrade specific organics not identified or not present in this study would be of value to determine those problem compounds that can be degraded at least in part to materials more amenable to subsequent aerobic treatment.

4. Further studies would also seem to be in order to delinate design parameters for a flocculent system following the anaerobic step. Use of a flocculent system could result in a cleaner effluent with no produced algae.

5. Further studies are needed to determine the types and threshold concentrations of compounds which inhibit anaerobic treatment. An initial project (#12020 FER) to partially fulfill this need is now being conducted by the grantee under partial sponsorship of the EPA Research, Development, and Demonstration Program.

SECTION III

INTRODUCTION

The only practical tools now available for treating soluble organics in large volumes of wastewater from a petrochemical plant are the aerobic biological systems, in particular the activated sludge and aerated stabilization processes (1,2). This study of anaerobic systems was undertaken to provide design engineers with an alternative approach potentially avoiding some of the problems characteristic in aerobic treatment and offering some performance improvements and economic advantages.

Difficulties encountered in the treatment of petrochemical wastes by conventional aerobic biological systems have been described in some detail in reporting the examination of a variety of treatment alternatives (3). One problem cited was the characteristic elevated temperature of these wastes which was detrimental to microorganism flocculation and separation. Also, contained surfactants cause foaming problems. The high temperature, surfactants, and the high rates of oxygen demand due to the concentrated wastes result in oxygen transfer problems and usually dictate the selection of long retention time and completely mixed systems in order to provide sufficient aeration equipment. Even at longer retention periods, peak oxygen demands often cannot be met with conventional equipment using air as a source of oxygen. Some of the synthetic organic constituents have been cited as inhibitory to nitrifiers (4), to protozoa, and possibly to flocculating organisms. The rapidly varying types and quantity of organics discharged from a large petrochemical complex result in non-equilibrium conditions in a high-rate biological process. Even in a situation where an efficiently operating aerobic system can be provided, the costs to aerate the system and to dispose of produced biological solids could make anaerobic treatment an attractive alternative.

Encouraging results from lightly loaded anaerobic lagoon systems at various plants and preliminary data in the literature attracted Union Carbide Corporation to conduct further studies of anaerobic processes as they apply to petrochemical wastes. Potential advantages of the anaerobic or combined anaerobic-aerobic process over the aerobic process alone were identified in initial work. In order to increase the scope of the study of anaerobic systems and to develop and disseminate the information in a form useful to others, a research grant was awarded by the Office of Research and Monitoring of the U. S. Environmental Protection Agency for partial support of in-depth anaerobic treatment studies by Union Carbide.

This report describes the anaerobic and aerobic treatment principles involved, including the advantages and disadvantages of each, the process steps studied, the methods and results used to select and develop an anaerobic treatment process for study in a demonstration pilot plant, the results of the pilot studies, and an economic evaluation of the selected system.

TREATMENT PRINCIPLES

Although the stepwise chemical reactions for the intracellular metabolism of organic chemicals by bacteria are complicated, more simple, over-all equations familiar to chemists and engineers may be written that describe the initial reactants and the final products (Table 1). The anaerobic reactions, known as fermentation and anaerobic respiration, occur in closed reactors or in the bottom of open lagoons and typically involve the reduction of carbon oxides, sulfates, nitrates, and organic molecules (5). Typical empirical equations also are included in Table 1 for photosynthetic processes and for the microbiological oxidation of organic compounds in which molecular oxygen is the electron acceptor. The biological cycles as they relate to the reactions listed in Table 1 are shown in Figure 1.

Several important economic and technical advantages inherent in the anaerobic treatment process are listed in Table 2 along with potential problem areas (6,7,8). Significant savings can result if the anaerobic and aerobic processes are joined to utilize the best features of each to compensate for some of their problems. This usually would involve utilizing a roughing anaerobic treatment followed by an aerobic treatment step for polishing of the wastewater.

Alternatives Tested

The first of three fairly well developed anaerobic processes selected for tests with petrochemical wastestreams was the contact digester (9) or "anaerobic activated sludge" system, Figure 2. The contact digester employs separation and recycle of produced biological solids to increase the concentration of organisms and their effective retention time within the digester. The increased organism retention time compensates for the long generation times of the critical methanogenic bacteria.

The anaerobic trickling filter (10) was the second process selected for study. Anaerobic filters utilize both the tendency of methane bacteria to grow on surfaces and the filtering capacity of a flooded, packed bed to overcome the long generation time of the methanogenic culture. The low solids production of the anaerobic system slows filter clogging when a low solids feed such as a petrochemical waste is treated.

The third anaerobic process selected for study was the anaerobic lagoon (11). Anaerobic lagoons are a low rate system which operate at low suspended microorganism concentrations and therefore require a relatively long retention time for adequate reduction of organic levels. The retention time required in a system is primarily a function of temperature and the amenability of the waste constituents to treatment by the various types of organisms involved.

Characteristics of the three systems studied are summarized in Table 3.

TABLE 1

TYPICAL BIOLOGICAL TREATMENT REACTIONS

I. Anaerobic Non-Photosynthetic Reactions (molecular oxygen absent)

A. Nitrate Reduction (Denitrification)

$$5CH_3COOH + 8NO_3^- \longrightarrow 10CO_2 + 4N_2 + 6H_2O + 8OH^-$$

$$5S + 6NO_3^- + 2H_2O \longrightarrow 5SO_4^= + 3N_2 + 4H^+$$

B. Sulfate Reduction

$$2CH_3CHOHCOOH + SO_4^= \longrightarrow 2CH_3COOH + 2CO_2 + H_2S + 2OH^-$$

$$4H_2 + SO_4^= \longrightarrow 2H_2O + H_2S + 2OH^-$$

C. Organic Carbon Reduction (Fermentation)

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$4CH_3OH \longrightarrow 3CH_4 + CO_2 + 2H_2O$$

$$C_6H_{12}O_6 \longrightarrow 3CH_3COOH$$

D. Carbon Dioxide Reduction

$$2CH_3CH_2OH + CO_2 \longrightarrow 2CH_3COOH + CH_4$$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

$$4H_2 + 2CO_2 \longrightarrow CH_3COOH + 2H_2O$$

II. Aerobic Non-Photosynthetic Bacterial Reactions

A. Oxygen-Limited Systems

$$CH_3CH_2OH + O_2 \longrightarrow CH_3COOH + H_2O$$

$$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$$

$$2CH_3CHOHCH_3 + O_2 \longrightarrow 2CH_3COCH_3 + 2H_2O$$

(continued)

TABLE 1 (continued)

II. Aerobic Non-Photosynthetic Bacterial Reactions (cont.)

B. Complete Oxidation

$$CH_3COOH + 2O_2 \longrightarrow 2CO_2 + H_2O$$

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

C. Nitrification

$$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

D. Sulfur Oxidation

$$2H_2S + O_2 \longrightarrow 2S + 2H_2O$$

$$2S + 2H_2O + 3O_2 \longrightarrow 2SO_4^= + 4H^+$$

$$S_2O_3^= + H_2O + 2O_2 \longrightarrow 2SO_4^= + 2H^+$$

E. Nitrogen Fixation

$$N_2 \longrightarrow \text{Nitrogenous Organics}$$

III. Photosynthetic Reactions

$$CO_2 + 2H_2S \xrightarrow{\text{light}} (CH_2O) + H_2O + 2S$$

$$3CO_2 + 2S + 5H_2O \xrightarrow{\text{light}} 3(CH_2O) + 4H^+ + 2SO_4^=$$

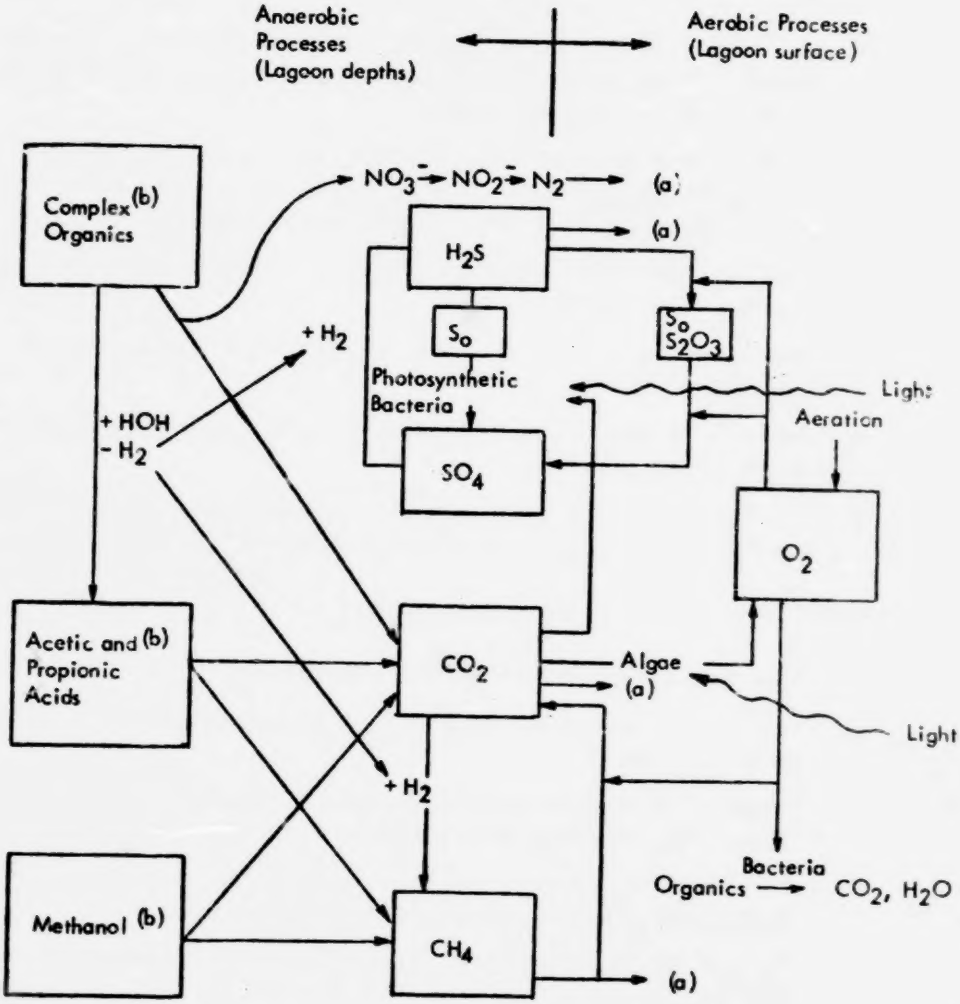
$$CO_2 + 2H_2O \xrightarrow{\text{light}} (CH_2O) + H_2O + O_2$$

$$9CH_3COOH \xrightarrow{\text{light}} 2CO_2 + 4(C_4H_6O_2) + 6H_2O$$

$$CO_2 + 2H_2 \xrightarrow{\text{light}} (CH_2O) + H_2O$$

$$2CH_3COOH + H_2 \xrightarrow{\text{light}} (C_4H_6O_2) + 2H_2O$$

FIGURE 1. BIOCHEMICAL PROCESSES


Anaerobic Processes (Lagoon depths)
Aerobic Processes (Lagoon surface)
Complex(b) Organics
$NO_3^- \rightarrow NO_2^- \rightarrow N_2 \rightarrow$ (a)
H_2S
(a)
S_o
S_o S_2O_3
$+H_2$
Photosynthetic Bacteria
Light
Aeration
+ HOH
$-H_2$
SO_4
O_2
Acetic and(b) Propionic Acids
CO_2
Algae
(a)
Light
$+H_2$
Bacteria
Organics → CO_2, H_2O
Methanol (b)
CH_4
(a)

(a) Possible gaseous emission to atmosphere

(b) Possible waste constituents

TABLE 2

ANAEROBIC TREATMENT CONSIDERATIONS

I. Advantages of Anaerobic Processes

A. No aeration equipment is required for organic reduction. Associated capital, power, and maintenance costs are avoided. System loading is not limited by oxygen transfer.

B. Cellular material is produced in lower quantity and more stable form. Savings in nutrients and in flocculants, equipment, and labor costs for biomass dewatering and final disposal can be realized.

C. Some problem organic chemicals difficult to degrade aerobically will degrade anaerobically.

D. The oxygen in nitrate and sulfate ions can be utilized for organic oxidation.

E. Methane in off-gas potentially can be used for heating or in odor control by incineration.

F. The anaerobic system can operate at temperatures at which a flocculant aerobic system experiences biomass separation difficulties (3).

II. Potential Problems with Anaerobic Processes

A. High temperatures are needed for maximum rates.

B. High biomass concentration is required for reasonable rates at short retention times.

C. Regeneration time for methane bacteria is long (2 to 11 days at 37°C), thereby requiring long solids retention and acclimation times.

D. Methanogenic microorganisms are reportedly more sensitive to shock loads, toxic materials, and environmental conditions.

E. Effluents low in BOD (<50 mg/l) with good aesthetic properties are difficult to produce.

F. Produced gases are odorous if released.

FIGURE 2

LABORATORY CONTACT DIGESTERS

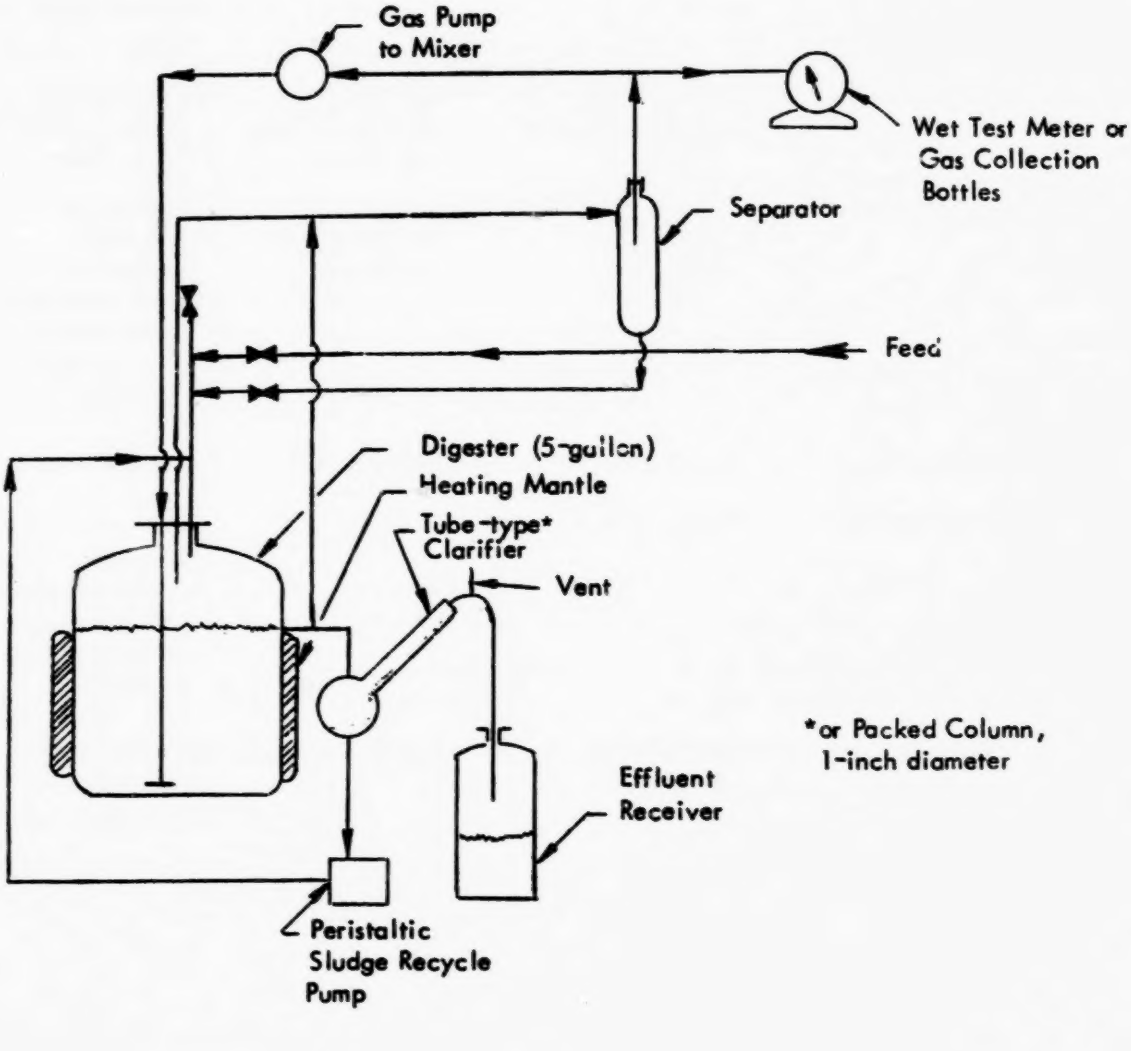

Gas Pump to Mixer
Wet Test Meter or Gas Collection Bottles
Separator
Feed
Digester (5-gallon)
Heating Mantle
Tube-type* Clarifier
Vent
*or Packed Column, 1-inch diameter
Effluent Receiver
Peristaltic Sludge Recycle Pump

TABLE 3

ANAEROBIC SYSTEMS STUDIED

	Submerged Filter	Contact Digester	Open Lagoon
Description	Rock or gravel packed column	Completely mixed vessel	Basin with considerable stratification
Flow pattern	Plug flow	Backmixed	Some wind and wave mixing, thermal turnovers
Biosolids level	High biomass through attached growths	High biomass through settling and return	Low suspended solids, bottom sludge layer
Metabolic pathways	Fermentation and anaerobic respiration	Fermentation and anaerobic respiration	Fermentation, anaerobic respiration, sulfur oxidation, photosynthesis, some aerobic respiration
Retention time	1 to 3 days	1 to 10 days	10 to 100 days
Gas collection	Normally collected	Collected	Gas is released, although a plastic covering with peripheral collection tiles is possible
Temperature control	Not normally practiced	Usually practiced	Unfeasible unless covered and insulated

SCOPE OF STUDY

The approach taken for the study was similar to that for chemical process development: a literature survey, bench-scale studies of several anaerobic processes to prove their feasibility under ideal conditions, semi-pilot studies of selected processes under less ideal operating conditions, and finally large-scale piloting of the best system. Economic evaluations were made concurrently to direct the development toward the most feasible area. The end result was a design basis for a large system for the anaerobic-aerobic treatment of petrochemical wastes.

Modifications of the three anaerobic processes were studied in bench-scale equipment using a simulated petrochemical waste to determine process feasibility with known, degradable substrates under well-controlled laboratory conditions. The studies were performed in laboratories at the Union Carbide Technical Center, South Charleston, West Virginia. The most promising systems were then tested under less ideal conditions feeding actual petrochemical wastes. The tests with real wastes under field conditions were originally planned for Union Carbide's Institute Plant at Institute, West Virginia. However, periodic inhibition with the wastes indicated a change in the study site and was the basis for the EPA Grant Number 12020-FER "Identification and Control of Petrochemical Pollutants Inhibiting the Anaerobic Processes." The tests were therefore conducted at Union Carbide's Texas City Plant to determine which of the processes worked best under field conditions. The Texas City Plant wastes had been previously shown to be amenable to anaerobic treatment in studies conducted by Union Carbide. The field studies were made with concurrent economic studies and comprised the basis for selection of one anaerobic process for testing in a large-scale unit. Large-scale process selection comprised the first of three phases envisioned in the over-all study.

The second phase was the design and construction of a pilot-scale demonstration unit using the anaerobic process selected as superior. The third phase included operation of the demonstration unit to optimize the process and to provide both economic and design data adaptable for a large-scale (at least 500,000 gal/day) plant.

Pilot scale aerobic treatment studies were made on the effluent of the anaerobic unit during the third phase. These studies provided information for designing and estimating the cost of a total treatment plant combining the roughing anaerobic treatment with the polishing aerobic treatment to produce a suitable effluent.

Selection of Process for Demonstration Study

Based on the economic and technical feasibility studies, the anaerobic lagoon process was concluded to be sufficiently promising to test on a pilot scale. This conclusion was based primarily on the following information obtained from the preliminary studies.

1. The investment estimated for both the anaerobic contact and filter processes exceeded that for the lagoon process at assumed favorable performance conditions for all three processes. This relationship should hold for waste less degradable than assumed in the estimates. The investment estimates assume land availability at a reasonable price.

2. In semi-pilot studies neither the anaerobic filter nor the contact process showed the reductions demonstrated in bench scale studies and assumed for the conditions of the economic study. Therefore, from a performance and economic standpoint they were even less attractive than the preliminary economic study indicated.

3. The need for further development of the lagoon process on a small semi-pilot scale was minimal, while considerable additional study on a semi-pilot scale was needed before the contact and filter processes could be considered.

4. The lagoon process was unique in its tolerance of sulfates in the feed through utilization of the sulfur oxidation-reduction cycle possible in the open-type system. It benefits from both anaerobic and aerobic conditions at the different levels in the lagoon.

5. According to the revised preliminary economic data the anaerobic-aerobic process had lower annual costs than did the aerobic process alone, as was postulated. Revised investment costs for both were similar (12).

6. Semi-pilot-scale studies of the aerated stabilization of anaerobic effluents have shown the feasibility of the aerobic treatment step of a combined treatment process.

7. The degradability of the Texas City Plant wastewater in open lagoons has been repeatedly confirmed.

8. Land availability and mild cold weather conditions at the Texas City, Texas location satisfy location requirements for a lagoon system.

SECTION IV

DEMONSTRATION SCALE PILOT PLANT

The demonstration-scale pilot facility consisted of the selected anaerobic lagoon process followed by an aerated stabilization process and facultative ponds for aerobic effluent polishing. A line drawing of the experimental facility is presented in Figure 3.

Two 50-by-100 foot anaerobic lagoons were used to determine the effect of depth on the lagoon process. The deeper lagoon (12 foot) had a capacity of 450,000 gallons while the volume of the shallower lagoon (6 foot) was 225,000 gallons. When operating at a 15-day retention time approximately 30 gpm of pretreated (clarified and neutralized) waste was fed to the two lagoons.

Aerated stabilization was accomplished in a 31,000 gallon open lagoon equipped with a surface aerator which accepted only a portion of the effluent from either lagoon. A flow of approximately 7 gpm was required to provide the desired 3-day retention time.

Two facultative lagoons each 6-feet deep and of 21,000 gallons' volume were used to settle effluent solids from the aerated stabilization basin and provide a polishing treatment.

The petrochemical waste treated in the pilot system was made up of the dilute waste from the Texas City Plant of Union Carbide Corporation. At times this dilute waste was supplemented with effluent from a long-retention-time lagoon system treating concentrated wastes and with the concentrated feed to this system. Properties of the wastes treated are described in Table 4.

The sampling and analytical schedule followed during the pilot study is listed in Table 5. Where composite samples are indicated the sample was collected in an iced container over the period of compositing. All samples were preserved by refrigeration between sampling and analysis.

The anaerobic lagoon demonstration system was operated to identify problems associated with scale up of the semi-pilot data, to determine the effects of depth on performance, and to provide design parameters. Aerobic units were operated to prove treatability of anaerobic effluent and to provide a design basis for economic comparison of the anaerobic-aerobic series process with completely aerobic systems.

FIGURE 3

FINAL ANAEROBIC-AEROBIC DEMONSTRATION SYSTEM

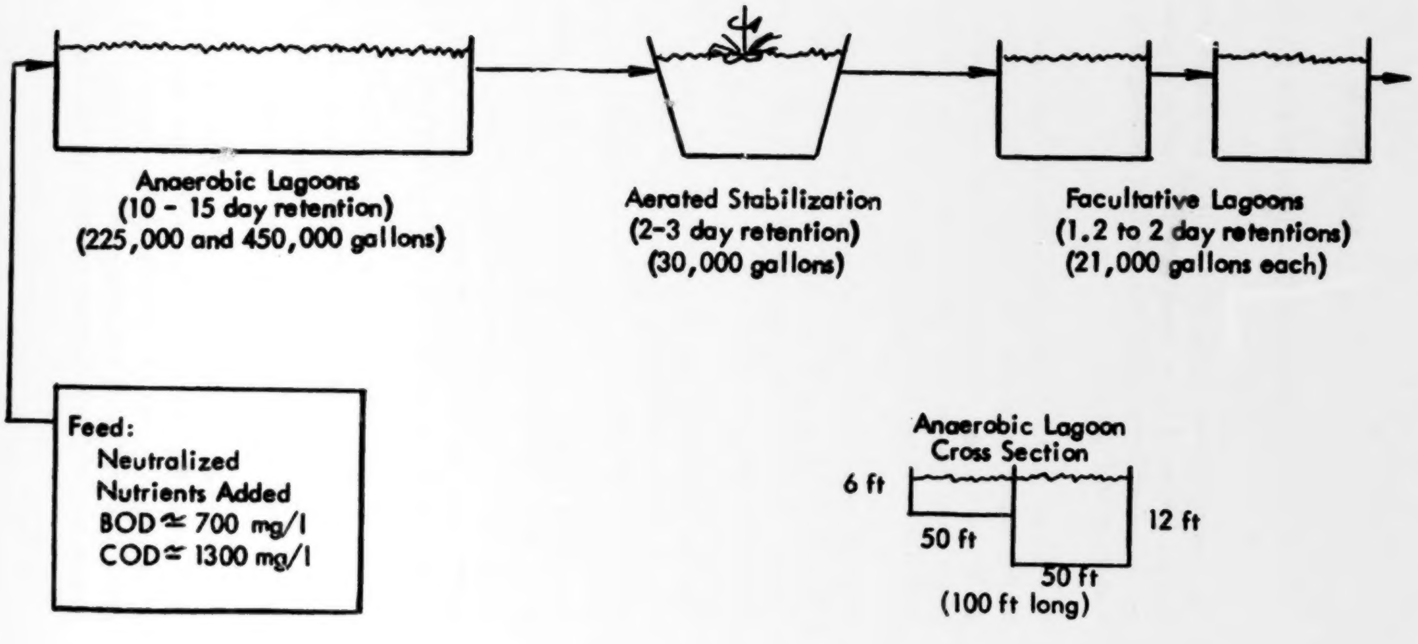

Anaerobic Lagoons
(10 - 15 day retention)
(225,000 and 450,000 gallons)
Aerated Stabilization
(2-3 day retention)
(30,000 gallons)
Facultative Lagoons
(1.2 to 2 day retentions)
(21,000 gallons each)
Feed:
Neutralized
Nutrients Added
BOD ≃ 700 mg/l
COD ≃ 1300 mg/l
Anaerobic Lagoon
Cross Section
6 ft
50 ft
12 ft
50 ft
(100 ft long)

TABLE 4

PROPERTIES OF WASTES TREATED

Property	Dilute Waste	Concentrated Lagoon Effluent	Concentrated Lagoon Feed
Temperature, °C	35 - 55	Ambient	Ambient
BOD, mg/l	400 - 800	600 - 1000	4000 - 7000
COD, mg/l	700 - 1600	3000	15,000
Alkalinity, mg/l as $CaCO_3$	--	4500	--
Total Carbon, mg/l	200 - 400	2500*	4000 - 6000
pH	6 - 11	8 - 9	7 - 9
$SO_4^{=}$, mg/l **	200 - 300	Very low (20)	600 - 700
Specific Volatile Organics	See Tables 12 and 13	Acetone Methyl ethyl ketone Methyl isobutyl ketone Volatile acids	Those present in dilute waste with the addition of Acetaldehyde Propionic acid Butyric acid Pentanol C_5-aldehydes C_5-acids C_6-alcohols Phenol Butyl ethers Propyl ethers Methyl isobutyl ketone C_{10-18} alcohols+ Formate+

* Total organic carbon, 1200 mg/l

+ Known to be present but not specifically identified

** Approx. 200 mg/l added from H_2SO_4 required for neutralization

TABLE 5

PILOT PLANT ANALYTICAL SCHEDULE

		Anaerobic Lagoons				Aerated	Facultative Lagoons		
		Basin		Effluent		Stabil.	Basin		Effluent
Type Analysis	Feed	East	West	East	West	Effluent	East	West	West
pH	M, G_1	G_1	G_1	G_1	G_1	G_1	G_1	G_1	G_1
COD (unfiltered and filtered)	C_3	--	--	C_3	C_3	G_1	--	--	G_3
BOD_5 (unfiltered)	C_3	--	--	C_3	C_3	G_1	--	--	G_3
BOD_5 (filtered)	--	--	--	--	--	G_1	--	--	G_1
Volatile acids	C_3	--	--	C_3	C_3	--	--	--	--
Alkalinity	C_3	G_1	G_1	C_3	C_3	G_1	--	--	G_3
Total suspended solids	C_3	--	--	C_3	C_3	G_1	--	--	G_3
Volatile suspended solids	C_3	--	--	C_3	C_3	G_1	--	--	G_3
Total organic carbon	O	--	--	O	O	O	--	--	O
Sulfur ($S^=$, $SO_4^=$)	SC_3	--	--	SG_1	SG_1	SG_1	--	--	SG_3
Phosphates	SC_3	--	--	SG_1	SG_1	SG_1	--	--	SG_3
Nitrogen (NH_4^+, NO_2^-, NO_3^-)	SC_3	--	--	SG_1	SG_1	SG_1	--	--	SG_3
BOD_{20} (total)	SC_3	--	--	SC_3	SC_3	SG_1	--	--	SG_3
Dissolved oxygen	--	--	--	--	--	G_1	--	--	--
Oxygen uptake	--	--	--	--	--	G_1	--	--	--
Microscopic examination	--	E	E	--	--	E	E	E	--
Specific organics (GLC)	SC_3	--	--	SC_3	SC_3	SG_1	--	--	SG_3
Total nitrogen (Dohrmann)	O	--	--	O	O	O	--	--	O
Profile	--	P	P	--	--	--	P	P	--
Temperature	G_1	G_1	G_1	--	--	G_1	G_1	G_1	--

(continued)

TABLE 5 (continued)

S = Four special one week studies during period of steady operation.

P = Depth and horizontal profiles of D.O., pH, ORP, Temp., $SO_4^{=}$, $S^{=}$, COD. Unscheduled (3 or 4 times during test period).

E = Microscopic examination for viable organisms and identification of types as required. Unscheduled.

M = Controlled or monitored continuously.

C_3 = Three-day composite of 24-hour samples (refrigerated).

G_1 = Grab daily.

C_1 = Daily continuously composited sample.

O = Readings taken occasionally during course of study.

G_3 = Composite of 3 daily grab samples (refrigerated).

SECTION V

ANAEROBIC LAGOON

The anaerobic lagoon system, due to its open surface, provides an environment suitable for not only the strictly anaerobic processes which occur in the contact digester and anaerobic filter but also facultative, photosynthetic, and aerobic processes at the surface. The wide variety of reactions possible is illustrated previously in Figure 1. Within the anaerobic depths illustrated at the extreme left of the figure, the classical acid-formation/methane-fermentation reaction steps are observed. The role of inorganic electron acceptors such as nitrate and sulfate in anaerobic respiration is depicted. In addition, some petrochemical waste components such as low molecular weight acids and alcohols may enter the cycle at an intermediate point and be converted directly to methane. The lagoon surface also provides an environment in which photosynthetic bacteria and algae may proliferate. Near the lagoon surface microaerophillic and facultative bacteria may utilize surface-entrained and photosynthetically produced oxygen in aerobic stabilization of organic wastes and inorganic reduced forms such as sulfides.

Two aspects of the complex biochemical relationships are of particular interest in petrochemical waste lagooning. Bacteria which are able to utilize volatile acids are important as these are generally present as components of the waste as well as produced metabolically within the system. If such bacteria were not present, the system acidity would increase, overcoming the buffer capacity and failure due to low pH would be certain. Bacterial groups of consequence in volatile acid metabolism are the classical methanogenic group and the photosynthetic purple sulfur and non-sulfur bacteria. Another potential mechanism for removal of volatile acids is aerobic oxidation in surface layers.

A second aspect of particular interest includes those bacterial and chemical reactions which comprise the lagoon sulfur cycle. In an uninhibited anaerobic system, influent sulfates will be reduced to sulfides with stabilization of organics. However, no net reduction in oxygen demand will take place unless the produced sulfides are either oxidized, lost to the atmosphere, or precipitated. Organisms which oxidize reduced sulfur forms are important both in reduction of oxygen demand and in maintaining a low level of sulfides, which would otherwise create serious odor problems and could be toxic to algae and methanogenic bacteria (13,14). The photosynthetic purple sulfur bacteria and microaerophillic sulfur bacteria are two bacterial groups which act to control sulfides, while atmospherically entrained and photosynthetically produced oxygen can chemically oxidize sulfides.

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The characteristics of anaerobic photosynthetic purple sulfur bacteria of the family Thiorhodaceae have been documented in standard textbooks in terms of ability to oxidize both sulfide and stored elemental sulfur to sulfate, uptake of organic materials, atmospheric nitrogen fixation, and proper environmental conditions for maximum growth. The seasonal variation of interactions between methane bacteria, purple sulfur bacteria, and algae in a lagoon treating domestic wastewater also has been studied (14).

Demonstration Lagoon Performance

During operation of the demonstration system a wide variety of both routine analytical determinations and special studies were performed both in the anaerobic segment and around the entire system. Experimental periods as segmented for temperature or loading conditions are itemized in Table 6 while routine operating and environmental data for the lagoons are presented in Table 7 and performance data are included in Table 8. Daily operating data for the entire system are included in Appendix I. A graphical presentation of performance indicating break points in feed and temperature is also included in Appendix I.

Lagoon performance was found to vary both with temperature and with volumetric loading rate (lb organic applied/unit volume-time) to the system. Some variation with the depth of the lagoon also was observed at higher loading rates.

As the demonstration study was operated over a relatively narrow range of loading conditions, data on performance in organic removal has been combined with the semi-pilot data collected in this study and data collected by Union Carbide from previous pilot and full scale lagoon studies for analysis. Combination of the data provides for prediction of lagoon performance under a wide range of conditions, and hence, wider applicability.

Experimental data utilized originate from lagoons ranging in size from 50 gallons (190 liters) to 450,000 gallons (1,700,000 liters) while full scale data originate from lagoons from 26 million to 180 million gallons. Lagoon volumes, waste strengths, nominal depths, and detention times are included in Table 9 while loading and removal data are included in Tables 8, 10, and 11.

The effectiveness of the lagoons in removal of oxygen demand was correlated with volumetric loading rate (lb waste/1000 cu ft-day) and temperature. In addition, an attempt was made to correlate removal with areal loading (lb waste/acre-day) for one temperature range. The effect of volumetric loading and temperature on COD removal is illustrated in Figure 4, while the observed relationship between

TABLE 6

ANAEROBIC LAGOON STUDY PERIODS

Date	
8-10 to 10-8-70	Dilute waste feed, warm temperature
10-9 to 11-2-70	Dilute waste feed, cooler temperature
11-3 to 2-7-71	Dilute waste feed, cold temperature
2-8 to 3-10-71	Dilute waste + previously treated anaerobic waste feed, cold temperature
3-11 to 4-14-71	Dilute waste + previously treated anaerobic waste feed, cool temperature
4-15 to 5-11-71	Dilute waste + additional concentrated feed, cool temperature
5-12 to 6-7-71	Dilute waste + additional concentrated feed, warm temperature
6-8 to 6-30-71	Dilute waste + additional concentrated feed, warm temperature

TABLE 7

ANAEROBIC LAGOON EXPERIMENTAL DATA

	Feed					No. 1 Lagoon, Deep							No. 2 Lagoon, Shallow						
Date	pH	Temp., °C (a)	COD_T (b), mg/l	BOD (d), mg/l	Volatile Acid, mg/l as HAc	pH	Temp., °C	COD_T (b), mg/l	COD_F (c), mg/l	BOD (d), mg/l	Volatile Acid, mg/l as HAc	Alkalinity, mg/l as $CaCO_3$	pH	Temp., °C	COD_T (b), mg/l	COD_F (c), mg/l	BOD (d), mg/l	Volatile Acid, mg/l as HAc	Alkalinity, mg/l as $CaCO_3$
8-10 to 10-8-70	6.7	41	1120	460	199	7.5	30	560	460	170	205	591	7.8	29	530	480	160	184	634
10-9 to 11-2-70	6.9	40	1120	550	133	7.4	25	530	360	150	269	520	7.6	25	530	380	180	199	639
11-3 to 2-7-71	6.7	39	990	480	151	7.3	20	580	520	180	184	456	7.4	19	580	500	190	173	482
2-8 to 3-10-71	7.0	33	970	420	160	7.0	17	660	610	210	232	389	7.1	17	600	550	190	222	386
3-11 to 4-14-71	6.7	32	1140	550	213	7.2	21	730	660	280	238	601	7.3	20	670	570	230	225	602
4-15 to 5-11-71	6.5	35	1780	640	360	7.3	24	1030	920	370	359	769	7.5	24	860	800	270	309	793
5-12 to 6-7-71	7.0	37	1600	790	376	7.1	27	930	830	440	465	827	7.3	27	830	770	410	441	833
6-8 to 6-30-71	6.5	40	2000	1180	686	7.1	29	1130	1070	600	686	942	7.3	29	1010	920	480	622	991

(a) Neutralization pit

(b) COD_T - Total COD

(c) COD_F - Filtered COD

(d) BOD - Total, 5 day BOD

TABLE 8

PERFORMANCE OF LAGOONS AT TWO DEPTHS

Period	Temp., °C	Feed Concentration, mg/l		Loading, lb/1000 cu ft-day (a)		Loading, lb/A-day				Removals, percent				Removal Difference Shallow-Deep, %	
						Deep		Shallow		Deep Lagoon		Shallow Lagoon			
		BOD	COD (b)	BOD	COD (b)	BOD	COD	BOD	COD	BOD	COD (b)	BOD	COD (b)	BOD	COD
8/10 - 10/8/70	30	460	1120	2.0	4.9	1050	2290	525	1150	64	50	65	53	1	3
10/9 - 11/2/70	25	550	1120	2.4	4.9	1250	2300	625	1150	74	53	67	53	-7	0
11/3/70 - 2/7/71	20	480	990	2.1	4.3	1080	2280	705	1140	62	41	60	41	-2	0
2/8 - 3/10/71	17	420	970	1.8	4.2	945	2190	470	1095	50	32	54	37	4	5
3/11 - 4/14/71	20	550	1140	2.4	4.9	1245	2570	620	1285	48	36	58	41	10	5
4/15 - 5/11/71	24	640	1780	2.8	7.7	1450	4025	725	2010	42	42	59	51	17	9
5/12 - 6/7/71	27	790	1600	3.4	7.0	1790	3633	890	1815	44	42	49	48	5	6
6/8 - 6/30/71	29	1180	2000	5.1	8.7	2670	4530	1335	2265	49	43	59	50	10	7

(a) lb/1000 cu ft-day x 16 = g/cu m-day

(b) Total COD

TABLE 9

ANAEROBIC LAGOONS STUDIED

Location	Lagoon Volume, gal (a)	Approximate Waste Strength, mg/l		Approximate Retention, days	Depth, ft
		COD	BOD		
Texas City Plant					
Full-Scale	26,000,000	8500	4500	30	1.5
	110,000,000	6000	3000	125	3.5
Pilot-Study	50(e)	1300-15,000	500-5800	4-40	3
	5,500 (e)	1200-3400	500-1600	5-15	3 (d)
	225,000 (b,e)	900-2000	400-1200	15	6
	450,000 (c,e)	900-2000	400-1200	15	12
Seadrift Plant					
Full-Scale	180,000,000		600	45	5

(a) gal x 3.785 = liters

(b) 6-feet (1.8 m) depth, 50 x 100-feet (15 x 30 m) surface

(c) 12-feet (3.7 m) depth, 50 x 100-feet (15 x 30 m) surface

(d) Computed as volume/surface area

(e) Part of 12020-DIS project

TABLE 10

DATA FROM UNION CARBIDE PILOT AND FULL SCALE STUDIES

Lagoon	Volume, gal.	Temperature, °C	Waste Strength, mg/l		Volumetric Loadings, lb/1000 cu ft-day		Areal Loading, lb/A-day		Removal, %	
			BOD	COD	BOD	COD	BOD	COD	BOD	COD
Texas City Plant	26,000,000	--	4510	8450	9.4	17.3	665	1200	33	30
		--	4440	8440	9.2	17.3	640	1200	39	31
		--	5500	--	6.6	--	460	--	58	--
Texas City Plant	110,000,000	--	2990	5900	0.88	1.7	133	262	66	46
		--	2685	5960	0.78	1.7	120	265	63	42
		--	2280	4450	1.2	2.2	175	340	65	29
Seadrift Plant	180,000,000	28	536	--	0.76	--	132	--	75	--
		22	527	--	0.92	--	160	--	75	--
		16	598	--	1.1	--	188	--	69	--
		24	547	--	1.4	--	237	--	76	--
		29	641	--	1.3	--	228	--	83	--
Texas City Plant	50	27	--	1360	--	8.8	--	960	--	56
		21	--	1420	--	9.2	--	1000	--	50
		31	--	1300	--	8.4	--	920	--	60
		13	--	1310	--	8.5	--	930	--	38
		8	--	1410	--	9.2	--	1000	--	30
		30	--	1270	--	8.3	--	900	--	54
		20	--	1385	--	8.9	--	970	--	46
		43	--	1295	--	8.4	--	915	--	48
		48	--	1410	--	9.2	--	996	--	23
		31	--	1240	--	8.0	--	877	--	57
		27	--	1330	--	8.6	--	938	--	43
		20	--	1380	--	9.0	--	975	--	46
		31	--	1245	--	8.1	--	881	--	56

(continued)

TABLE 10 (continued)

Lagoon	Volume, gal.	Temperature, °C	Waste Strength, mg/l		Volumetric Loadings, lb/1000 cu ft-day		Areal Loading, lb/A-day		Removal, %	
			BOD	COD	BOD	COD	BOD	COD	BOD	COD
Texas City Plant	5500 (a)	23	580	1200	3.8	7.8	490	1020	47	24
		30	550	1100	3.6	7.1	470	930	73	42
		27	490	1230	3.2	8.0	415	1050	76	52
		23	680	1260	4.4	8.2	575	1075	67	53
		28	630	1260	4.1	8.2	540	1070	73	52
		28	--	1620	--	10.5	--	1370	--	50
		28	1053	2150	14.0	28.0	1830	3660	30	30
		26	1480	1930	12.0	25.0	1570	3270	20	19
		19	1080	2000	7.0	13.0	920	1695	45	37
		15	1080	2160	7.0	14.0	920	1830	48	42
		10	1080	2160	7.0	14.0	920	1830	43	40
		17	925	2160	6.0	14.0	785	1830	54	45
		13	1390	3080	9.0	20.0	1175	2615	34	30
		19	1540	3400	10.0	22.0	1310	2875	40	33
		22	1500	3240	13.0	28.0	1700	3660	52	37
		13	1620	3000	7.0	13.0	915	1700	46	32
		19	1390	3000	6.0	13.0	785	1700	52	37
		22	1050	2300	5.0	10.0	655	1310	68	49
		23	810	1740	7.0	15.0	915	1960	62	45
		28	1040	3020	9.0	26.0	1175	3400	62	38
		29	1230	3080	8.0	20.0	1045	2615	54	42

(a) Lagoon of an irregular, prismoid shape. Effective depth computed as volume/surface area.

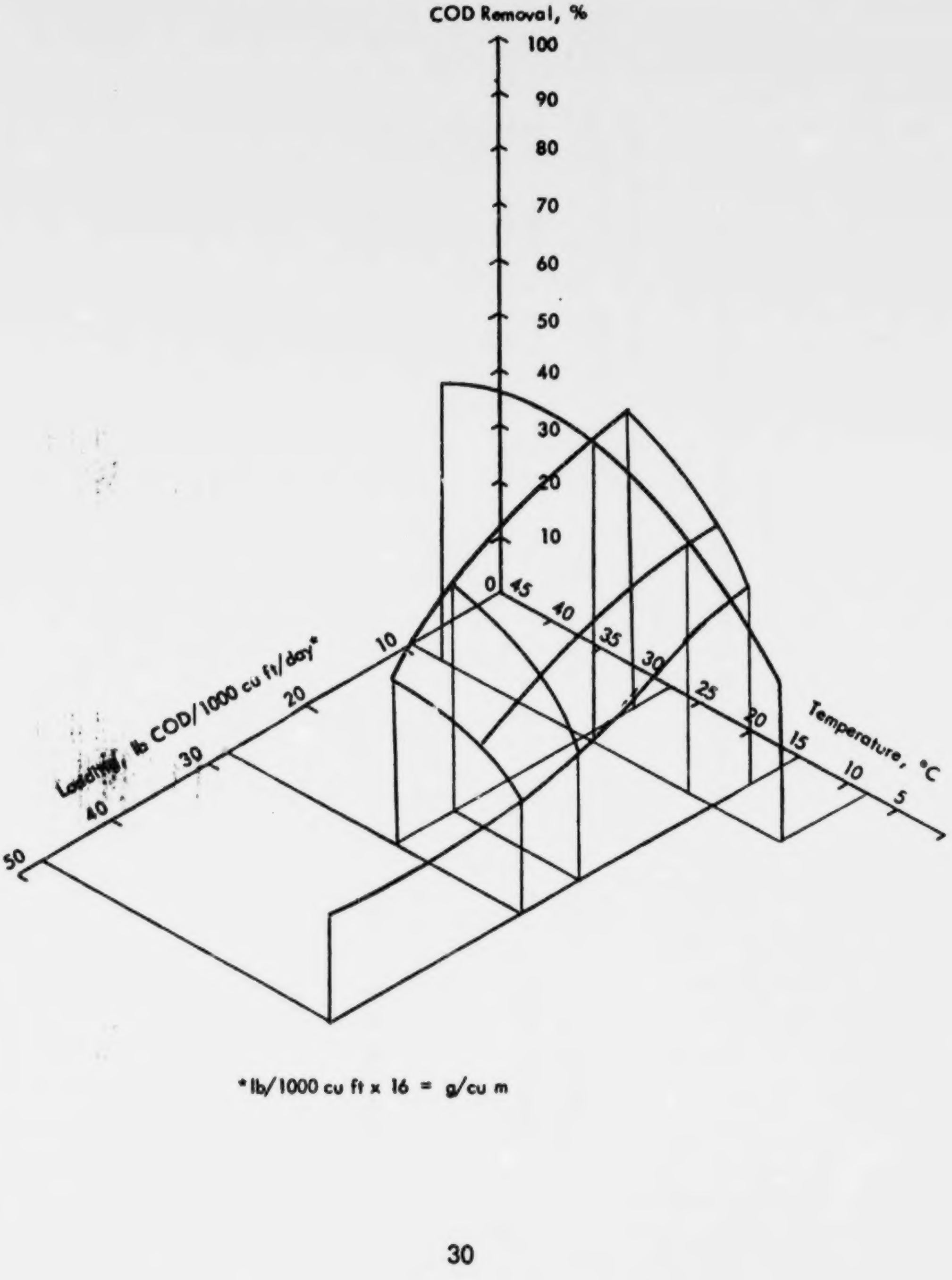
TABLE 11

DATA FROM EPA SPONSORED SEMI-PILOT LAGOON STUDIES

Lagoon	Volume	Temperature, °C	Waste Strength, mg/l		Volumetric Loading, lb/1000 cu ft-day		Areal Loading, lb/A-day		Removal, %	
			BOD	COD	BOD	COD	BOD	COD	BOD	COD
Texas City Plant	50	15	5800	14,600	18.8	47.5	2050	5175	18	18
		15	5800	14,600	9.4	22.2	1030	2420	34	23
		14	--	1,490	--	24.4	--	2660	--	26
		14	--	1,480	--	12.1	--	1320	--	34
		14	--	1,380	--	11.3	--	1230	--	34
Texas City Plant	5500	15	685	1,510	5.8	12.8	760	1675	36	29

FIGURE 4

COD REMOVAL AS A FUNCTION OF LOADING AND TEMPERATURE



*lb/1000 cu ft x 16 = g/cu m

BOD and COD removal is shown in Figure 5. Efficiency is seen to be highest at warmer temperatures and light loading rates and to decrease with either a temperature drop or a load increase. Figures 6-8 indicate the performance variation resulting from changing one variable while the other variables are held constant and illustrate the fit of the data points about BOD and COD removal lines. Figure 6 indicates that removal efficiency decreases above a maximum temperature of approximately 43 °C at a loading of 8-9 lb COD/1000 cu ft-day (130-140 g/cu m-day). Temperatures were varied by artifically heating or cooling reactors and therefore do not necessarily represent actual conditions in a Gulf Coast location. In Figures 7 and 8 the effect of varying loading on performance in terms of COD and BOD removal respectively is illustrated.

A correlation between areal loading and COD removal at a temperature of 26 to 31 °C is presented in Figure 9. A particular discrepancy is noted between removals from the twelve foot deep pilot system and the 5500 gallon semi-pilot lagoon at loadings of approximately 3500 lb COD/A-day. Areal loading is related to volumetric loading as

$$\text{Areal Loading (lb/A-day)} = \text{Volumetric Loading (lb/1000 cu ft-day)}\ (43.56)(\text{Depth, ft}).$$

Since the deep pilot scale system had a depth of four times that of the semi-pilot lagoon a volumetric loading four times larger must have existed in the semi-pilot lagoon for an equal areal loading. The large reduction in performance in the semi-pilot lagoon correlates well with the volumetric loading plot (Figure 7). Due to the discrepancies observed in comparing data using an areal loading correlation and the good agreement with volumetric loading, the volumetric loading rate was selected as a design parameter.

Since a given volumetric loading may occur from a number of combinations of waste strengths and retention times, the source of the data used in this study needs to be defined. The maximum loading rates in Figure 4 were obtained using concentrated wastes in 20- and 40-day retention 50-gallon reactors. These same wastes are treated acceptably in actual lagoons of longer retention time (lower loading rate) at the Texas City Plant. Minimum loading rates were observed with dilute wastes in retention times from 5 to 15 days and concentrated wastes in extremely long retention ponds.

For a given volumetric loading rate the large differences in hydraulic retention time due to varying waste strengths result in changes in surface cooling during the critical winter periods. For example, at the same volumetric loading a concentrated waste is retained longer than is a dilute waste; and the increased retention

FIGURE 5

RELATIONSHIP BETWEEN BOD AND COD REMOVAL

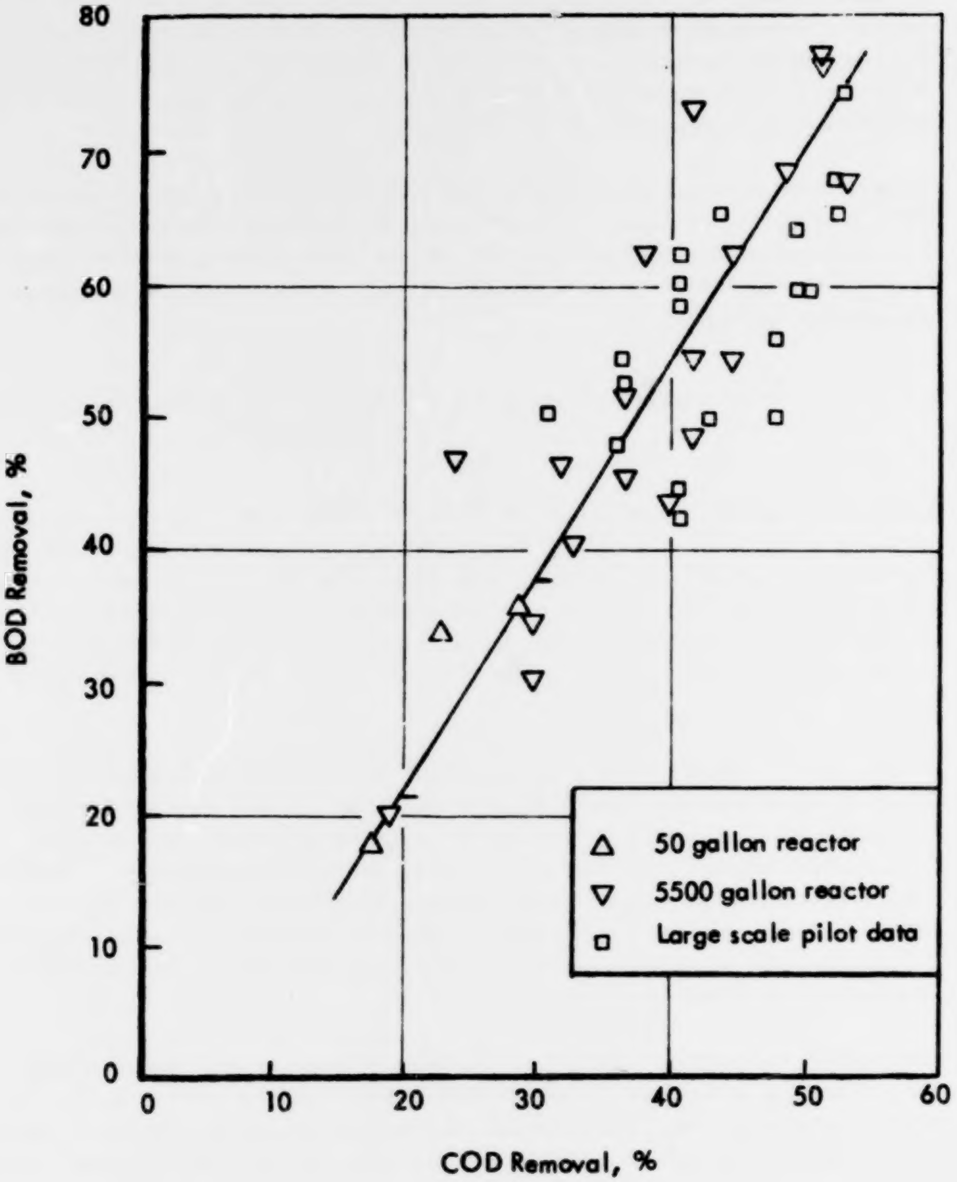


FIGURE 6
ORGANIC REMOVAL AS A FUNCTION OF TEMPERATURE

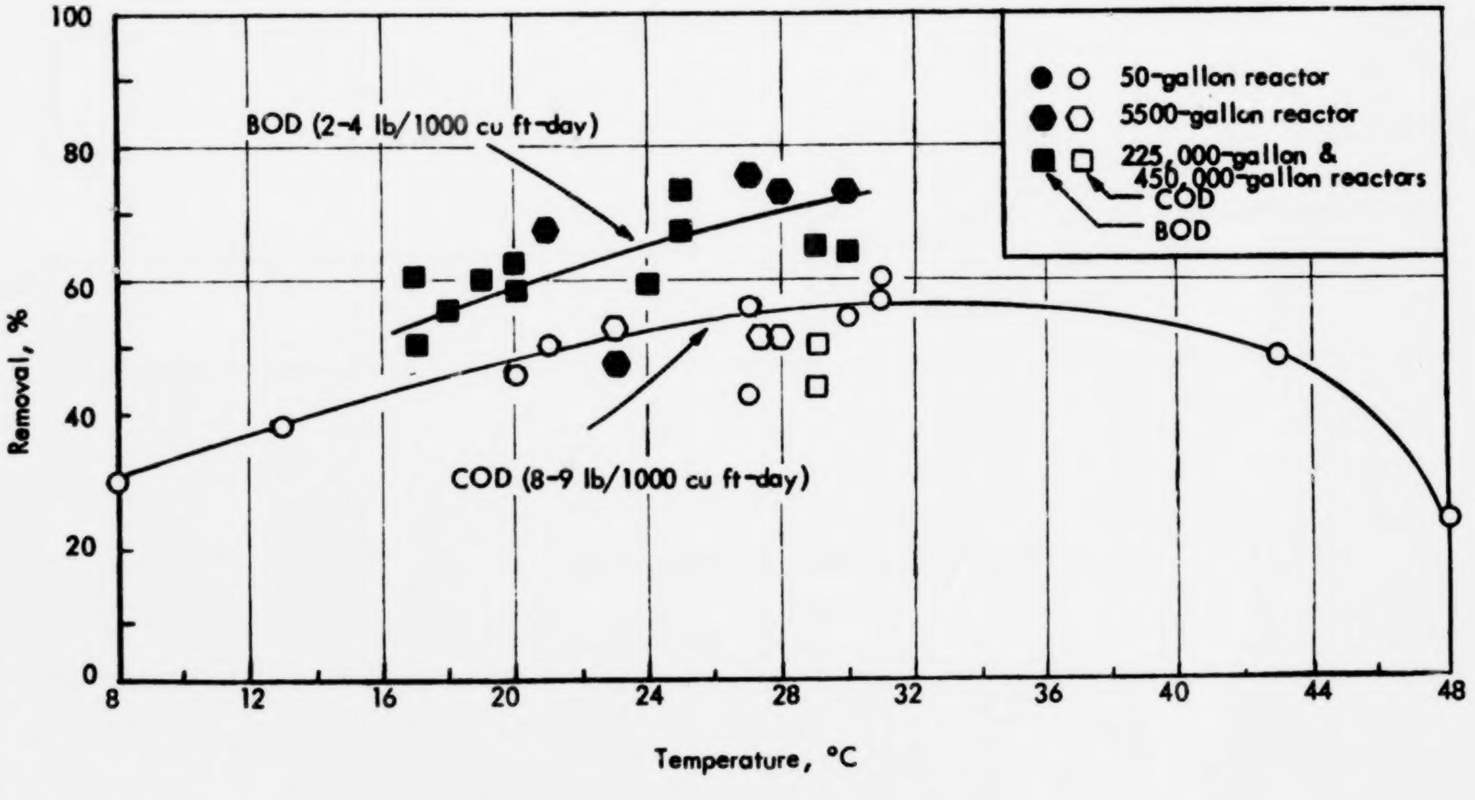


FIGURE 7

COD REMOVAL AS A FUNCTION OF LOADING

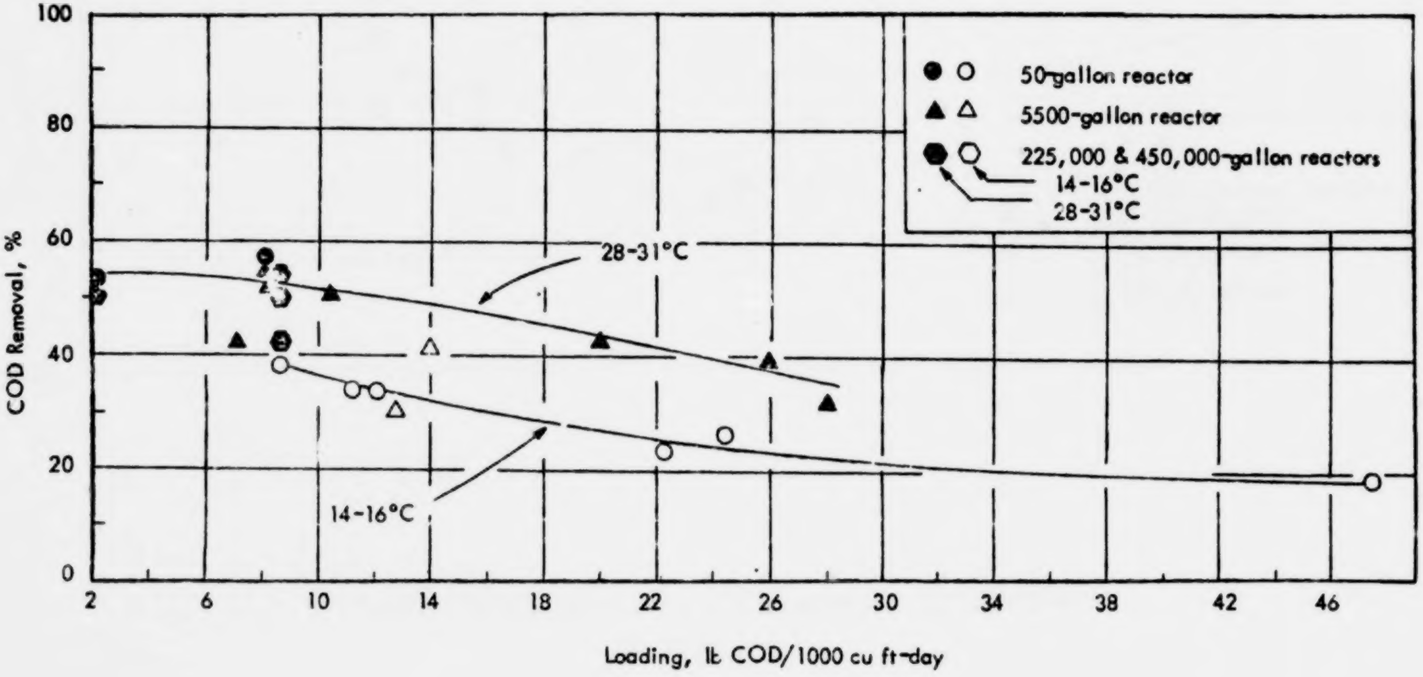


FIGURE 8

BOD REMOVAL AS A FUNCTION OF LOADING

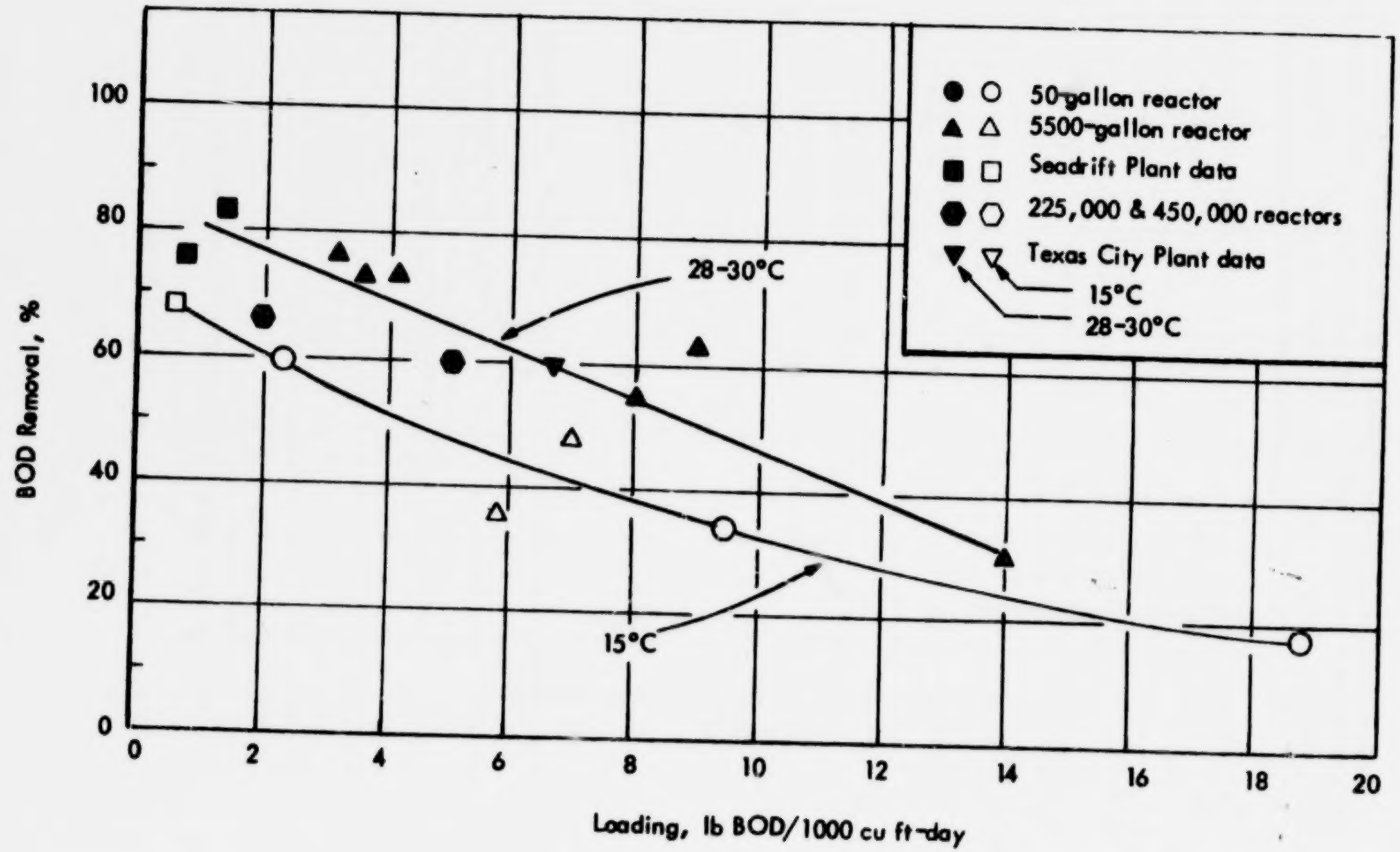
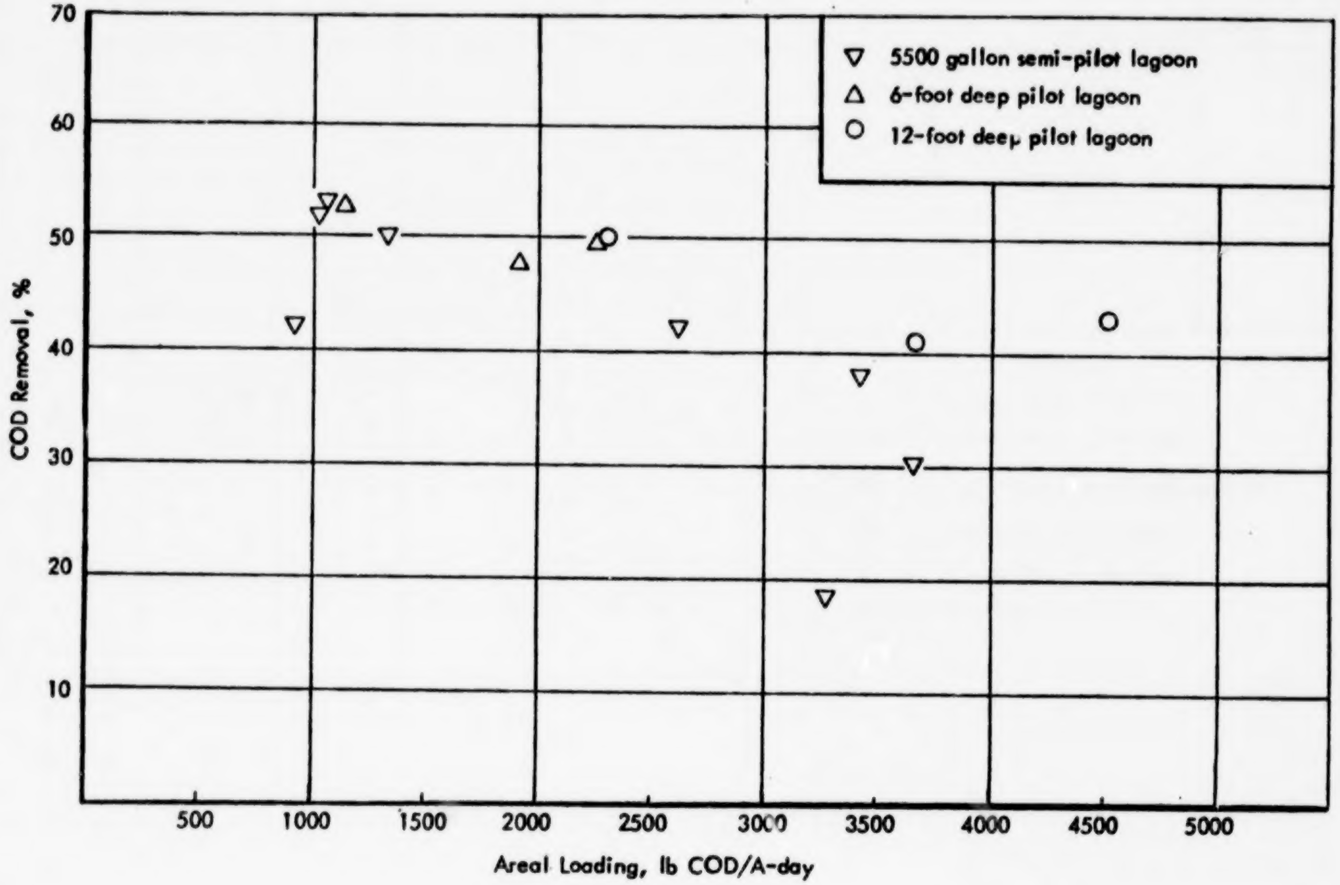


FIGURE 9

COD REMOVAL VERSUS AREAL LOADING AT 26 TO 31°C



retention results in a lower temperature and a consequent depression in performance. Relationships between loading, temperature, and resultant removals, therefore, must be considered for use of the curves in design. Figures 10 and 11 provide a method of evaluating various alternatives for a desired removal.

In Figure 10 the three-dimensional Figure 4 is reduced to a topographic plot of constant removal with temperature and loading. The area under the constant percentage removal line incorporates temperature and loading conditions that represent a removal of that level or greater. The lengths of line presented for each removal level indicate the limits of available data from this study. As lower temperatures and loadings are most generally critical, the curves define the area of greatest interest.

Application of these relationships would typically start from a known waste strength with an estimation of volumetric loading. The associated retention time and lagoon volume are computed from Equations 1, 2, and 3.

$$\text{Retention (days)} = \frac{\text{Influent concentration (mg/l)} \times 62.4}{\text{Desired loading (lb/1000 cu ft-day)} \times 10^3} \qquad (1)$$

$$\text{or} \qquad = \frac{\text{Influent concentration (mg/l)}}{\text{Desired loading (gm/cu m-day)}} \qquad (2)$$

$$\text{Volume (gal)} = \text{Flow (gal/day)} \times \text{Retention (days)} \qquad (3)$$

A reasonable combination of volumetric loading and temperature level to provide the desired organic reduction is assumed from Figure 10. For example, ambient temperature might be assumed in computations of an original loading rate. With a known organic concentration and an assumed loading, a depth must be selected. The depth will depend upon the influent sulfate load, land availability, land cost, and the removal efficiency required. An expected lagoon temperature can then be estimated for any selected load using a relationship such as that suggested for cooling water ponds by Brady et al (15). Figure 11 illustrates the predicted temperature with a variety of waste loadings and influent organic levels for a winter period in a Houston-Galveston location. Temperatures were computed assuming an influent temperature of 50°C, a depth of 10 feet, and a completely mixed condition. For a given loading, as the waste concentration increases, a longer retention period and consequently more cooling results in a lower temperature.

FIGURE 10
COD REMOVAL AS A FUNCTION OF LOADING AND TEMPERATURE

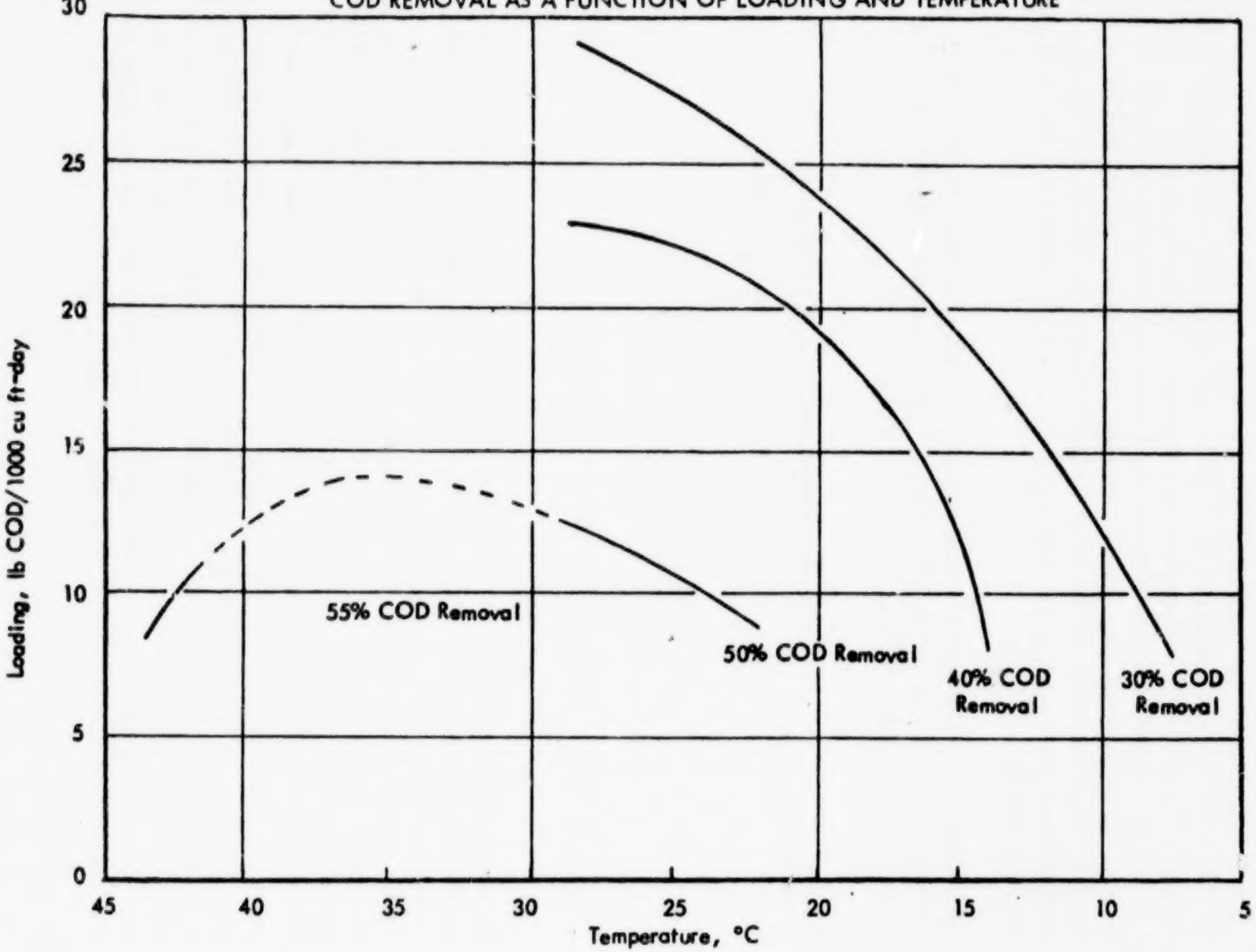
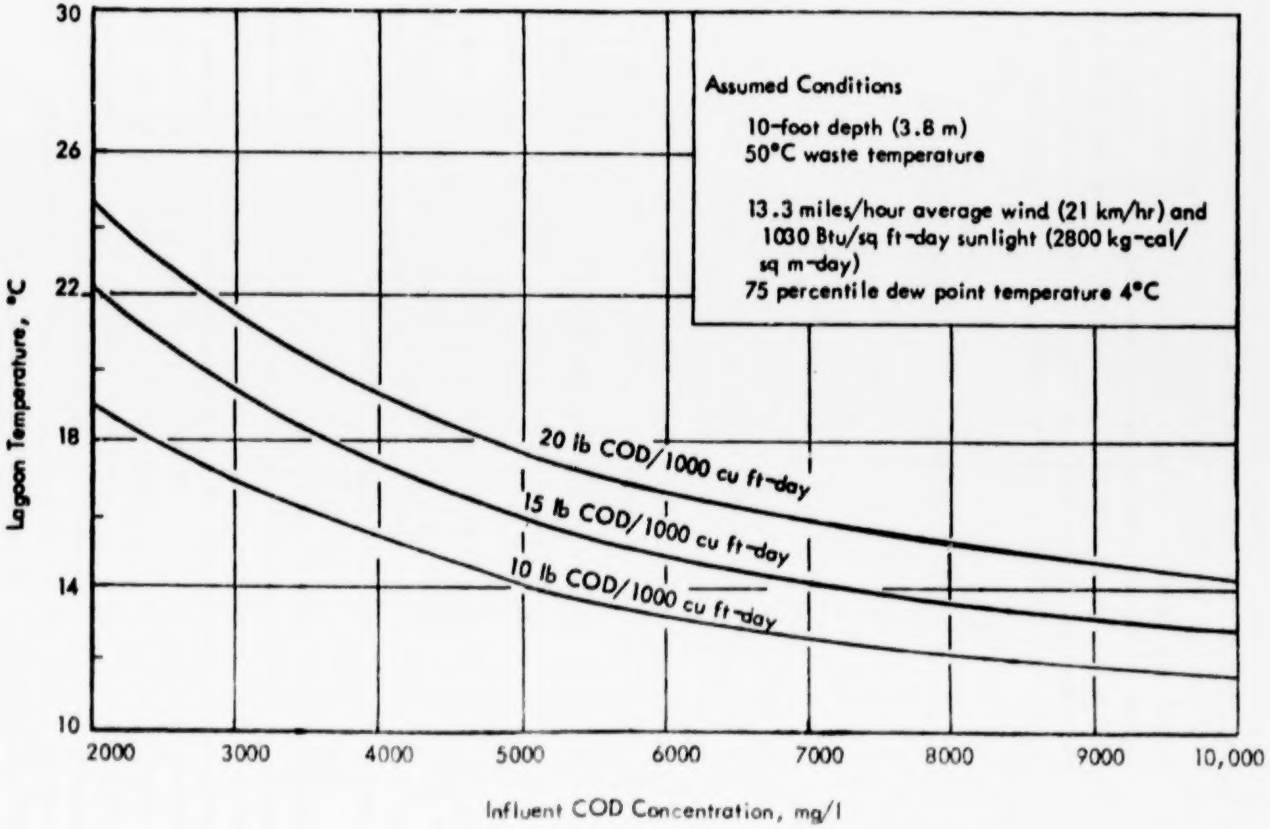


FIGURE 11

PREDICTED LAGOON TEMPERATURES IN JANUARY, HOUSTON-GALVESTON AREA



The following example illustrates the utility of the developed relationships. Cooling, equalization, and a 50 percent minimum BOD removal are required prior to aerobic treatment for a 3 mgd (11,000 cu m/day) flow containing 3000 mg/l COD at a Gulf Coast location near Houston, Texas. Also assume that influent sulfates are low so that the lagoon system may be constructed reasonably deep, about 10 ft (3 m). Relating to Figure 5 to obtain a BOD removal of 50 percent a COD removal of 40 percent would be reasonable in design. Figure 10 indicates that such a removal could be met at the following loading-temperature conditions:

Loading, lb COD/ 1000 cu ft-day	Required Temperature, °C
10	14
15	17
20	21

Examination of Figure 11 for an actual temperature at the three loadings indicates that at the 20 lb/1000 cu ft-day (320 g/cu m-day) loading, the required minimum temperature of 21 °C just can be maintained while at the two lower loadings, a temperature warmer than required and hence, larger removals would occur. Such a loading would require a retention time of

$$\frac{3000 \text{ mg/l} \times 62.4}{20 \text{ lb/1000 cu ft-day} \times 10^3} = 9.4 \text{ days}$$

or a lagoon of approximately 9 acres (3.6 ha) would be required at the assumed 10-ft (3 m) depth. Assuming the lagoon maintained approximately ambient temperature in the warmer months a removal of approximately 45 percent COD (60 percent BOD) would be expected (Figure 5).

Although gross performance parameters are of interest in overall design, the utility of the lagooning process in removal of specific materials is needed when determining its applicability to any given waste stream. Removal of specific volatile organic compounds from lagoons receiving petrochemical wastes has been monitored by gas chromatographic techniques for two lagoon loading rates with a concentrated waste (15,000 mg/l COD), for one loading with a dilute waste (1500 mg/l COD) and for the demonstration system. As presented in Tables 12 and 13, the more lightly loaded of the systems treating concentrated waste (22 lb COD/1000 cu ft-day) provided a slightly lower effluent concentration of virtually all the detected influents and less volatile acids than did the more heavily loaded system (48 lb COD/1000 cu ft-day). The lagoon treating dilute wastes (13 lb COD/1000 cu ft-day) showed an average reduction in detected materials, excluding acetic acid, of about 60 percent. The lagoons treating dilute wastes contained none of the produced propionic and butyric acids which were observed in the concentrated system, possibly due to different

TABLE 12

REMOVAL OF SPECIFIC ORGANICS IN SEMI-PILOT SCALE ANAEROBIC LAGOONS

	Dilute Wastes 13 lb COD/1000 cu ft-day								Concentrated Wastes											
	Influent (mg/l)				Effluent (mg/l)				Influent (mg/l)				22 lb COD/1000 cu ft-day Effluent (mg/l)				48 lb COD/1000 cu ft-day Effluent (mg/l)			
Compound	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences
Methanol	80	134	40	10	35	67	13	7	380	400	294	8	135	187	107	7	145	200	120	9
Ethanol	80	134	38	11	15	19	10	6	270	480	144	6	120	144	48	7	130	144	96	9
n-Propanol	--	--	--	--	--	--	--	--	170	584	33	5	35	84	17	5	40	84	17	6
Isopropanol	60	134	17	11	30	84	17	11	175	376	125	9	45	84	42	7	55	84	42	8
n-Butanol	--	--	--	--	--	--	--	--	170	246	77	7	75	123	38	4	80	116	62	4
Isobutanol	--	--	--	--	--	--	--	--	250	711	77	8	80	139	31	4	85	123	38	4
n-Pentanol																				
Isopentanol	--	--	--	--	--	--	--	--	315	735	162	9	70	88	44	4	100	184	59	8
Hexanol	--	--	--	--	--	--	--	--	140	355	71	9	20	36	21	4	30	71	14	6
Acetaldehyde	30	101	18	14	10	18	9	7	80	92	46	9	35	92	18	5	40	92	18	5
n-Butyraldehyde	--	--	--	--	--	--	--	--	190	450	68	7	50	112	22	5	35	75	15	6
Isobutyraldehyde	--	--	--	--	--	--	--	--	210	450	98	7	50	75	22	5	50	75	15	7
Acetone	60	89	32	11	39	48	16	10	100	128	80	9	53	80	40	7	47	80	40	8
Methyl ethyl ketone	15	30	8	10	8	8	8	7	--	--	--	--	--	--	--	--	--	--	--	--
Benzene	10	11	5	10	5	5	5	6	--	--	--	--	--	--	--	--	--	--	--	--
Ethylene glycol	135	232	103	11	30	39	26	6	755	1420	387	9	155	322	77	6	190	387	103	8
Acetic acid	215	300	100	10	220	500	75	11	2120	3440	1000	9	2280	3380	1300	7	2620	4000	1400	9
Propionic acid	--	--	--	--	--	--	--	--	0	--	--	9	505	824	196	7	470	772	185	7
Butyric acid	--	--	--	--	--	--	--	--	0	--	--	9	330	448	96	7	300	320	128	6

Note: Data are averaged from 5 to 12 occurrences in grab or composite samples.

Average temperature for all systems 15°C

Depth of lagoons treating concentrated waste was 3 ft, 2.5 ft for dilute waste

Detention times were 40 days (22 lb COD/1000 cu ft-day), 20 days (48 lb COD/1000 cu ft-day) and 7.5 to 10 days (13 lb COD/1000 cu ft-day).

TABLE 13

REMOVAL OF SPECIFIC ORGANICS IN PILOT SCALE ANAEROBIC LAGOONS

	Influent				Effluent							
					Deep Lagoon				Shallow Lagoon			
Compound, mg/l	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences	Mean	Max	Min	Number of Occurrences
Methanol	74	107	53	12	27	27	27	1	27	27	27	1
Ethanol	111	230	38	12	12	19	10	4	10	10	10	5
n-Propanol	25	58	17	10	8	8	8	1	+	--	--	--
Isopropanol	28	58	17	7	10	17	8	3	8	8	8	4
Acetaldehyde	24	37	18	3	+	--	--	--	+	--	--	--
Acetone	31	48	16	12	14	24	8	9	11	16	8	9
Methyl ethyl ketone	15	22	8	4	7	7	7	2	7	7	7	2
Benzene	6	10	5	9	+	--	--	--	+	--	--	--
Ethyl acetate	9	9	9	5	+	--	--	--	+	--	--	--
Ethylene glycol	124	168	77	12	26	26	26	1	26	26	26	1
Acetic acid	140	188	112	12	118	125	62	6	122	175	25	7
Propionic acid	31	31	31	1	16	21	10	2	10	10	10	1

+ Compound not detected in lagoon effluent

Deep lagoon 12 feet deep
Shallow lagoon 6 feet deep
Detention time = 15 days
Temperature ranged from 17 to 30°C

wastes. Analysis of removal data on an unsteady feed could be misleading since the effects of feed dilution into a large volume, weathering, and concentration are not taken into account. However, based on the five to twelve occurrences in the composite and grab samples collected, all of the detected materials except metabolic intermediates such as volatile acids appear to be removed to a significant degree in the anaerobic lagoon pretreatment process.

Mixing and Tracer Studies

A tracer study was made in the deeper pilot lagoon to determine whether short circuiting, leakage, or vertical liquid stratification would be a problem in system operation or scaling. The tracer results also provide a measure of the equalization capacity of the lagoon.

A lithium tracer was added to the deep lagoon feed as a spike on December 22, 1970. The winter period was selected for testing since the potential for thermal stratification and short circuiting (maximum temperature differential between waste, 40°C temperature, and lagoon contents, 14 to 22°C) should be greatest. Initial samples were collected at 0.1, 6, and 11 foot depths near the lagoon inlet at intervals of 1, 3, 6 and 24 hours after dosing. Samples were also collected at 0.1, 3, and 11 foot depths near the lagoon effluent at intervals of 1, 3, 5, 7, 9, 13, and 16 days. Lithium profiles with time are presented in Figures 12 and 13.

Profile data at the lagoon inlet indicate a rapid rise in lithium concentration at the 0.1 and 6 foot depths near the inlet. No peak in concentration was seen at the sludge layer. After a 9 hour period the concentration had attained a uniform level at all three depths indicating complete vertical mixing. Data collected near the effluent show that a uniform vertical distribution was present. The time of arrival of the peak concentration was approximately 4 days at the 6 foot depth while the extended shape of the tracer curve indicates longitudinal distribution approaching a completely mix condition after 5 to 6 days' retention.

Analysis of the water in the shallow lagoon and surrounding the deep lagoon indicating a maximum concentration of 0.1 mg/l lithium compared to the 1 to 2 mg/l level in the lagoon.

Functional Tests

A number of experiments have been made to estimate the impact of various microbial groups on lagoon performance and to trace hydraulic properties within the demonstration lagoon. Emphasis was placed on volatile acid and sulfur metabolism. Two techniques were used in studying the influence of various cultures on lagoon performance.

FIGURE 12
LITHIUM PROFILES AT LAGOON INFLUENT

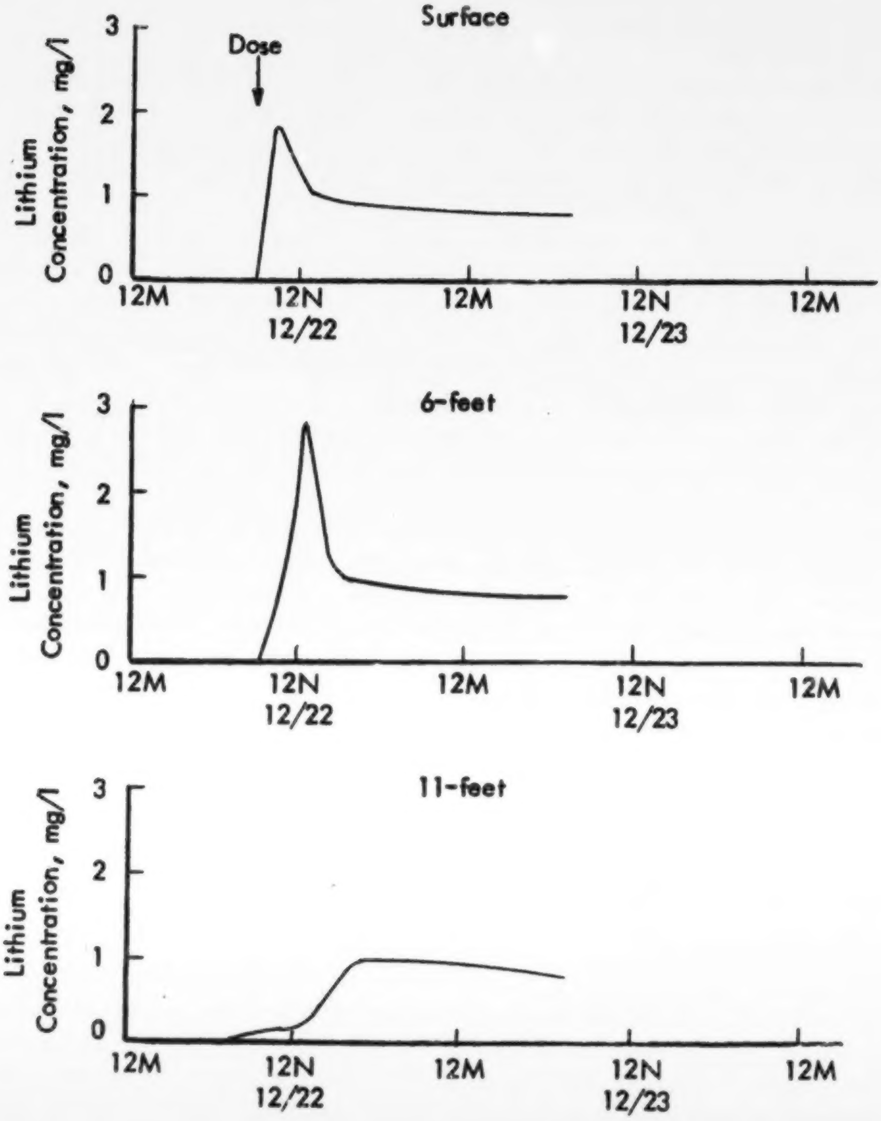
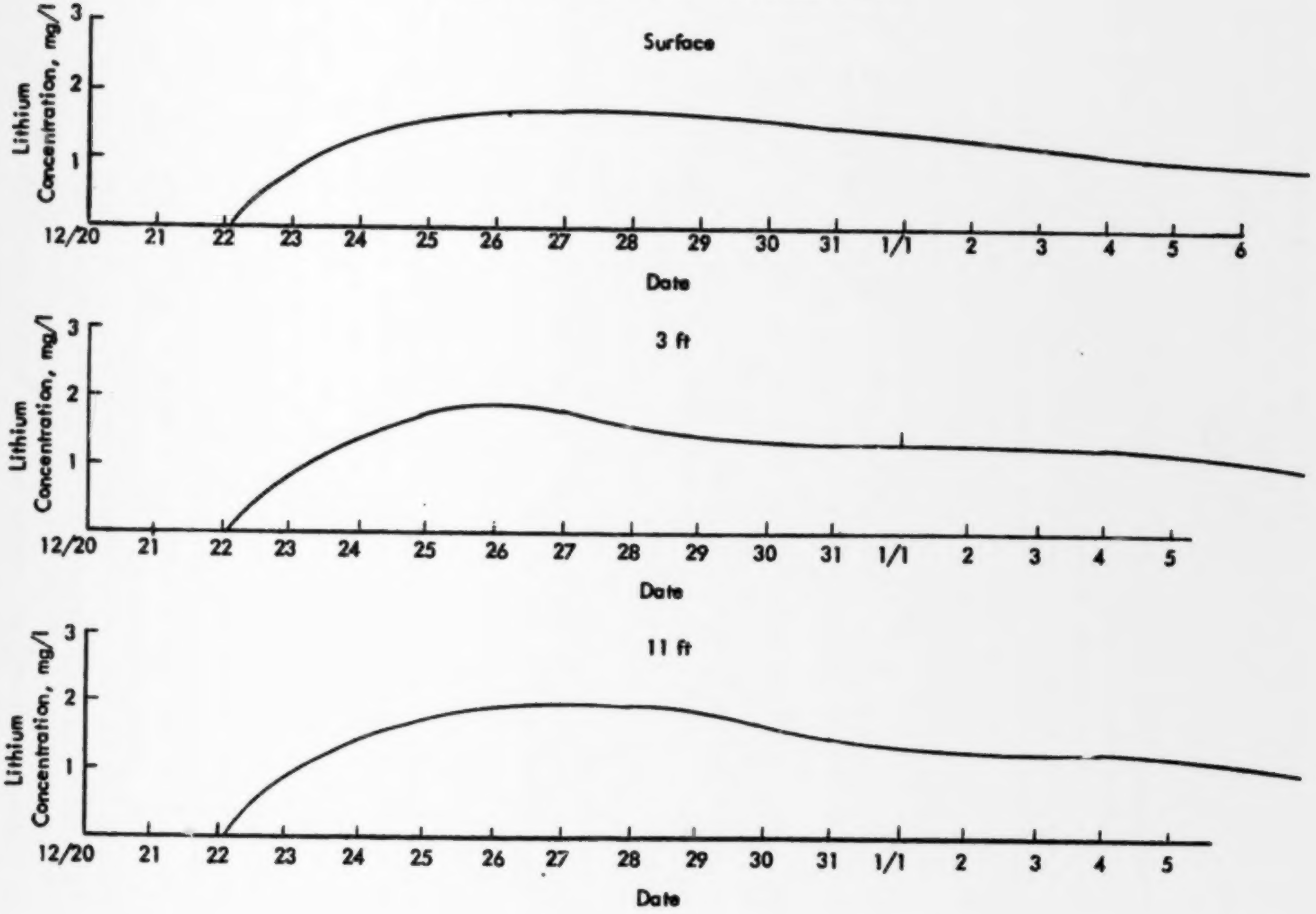


FIGURE 13

LITHIUM PROFILES NEAR LAGOON EFFLUENT



Continuous experiments were performed in the two large experimental lagoons constructed under the demonstration phase of the project. During the 11-month duration of the study diurnal profiles of sulfur compounds, COD, volatile acids, pH and temperature occasionally were made.

Batch studies of both methanogenic and photosynthetic activities were made by innoculating waste or synthetic substrates with biota from the demonstration lagoon system and incubating the mixture under either the original or an artificially imposed environment. In the case of methanogenic studies, 1.5 liters of bottom sludges were mixed with 1.5 liters of waste or waste and dilution water to a 1.5 l volume in a one-gallon (3.8 liters) container as illustrated in Figure 14. Gas was collected by displacement in an inverted graduated cylinder. The reactor contents were mixed daily, and samples were withdrawn at various intervals for analysis of total soluble COD, soluble organic COD (sulfides removed by acidification and nitrogen stripping), total carbon, total organic carbon, sulfates, sulfides, volatile acids, and pH. Bottom sludge reactors were incubated at ambient temperature.

Batch tests of photosynthetic activity were made by filling a standard 300-ml BOD bottle with 240 ml of lagoon liquor from the desired level and test material, dilution water, or a combination to bring the total volume to 300 ml. One half of the prepared samples were covered with aluminum foil to maintain a dark condition. Samples were then incubated under ambient temperature conditions either in a continually lighted bath for studies of maximum photosynthetic activity or within the lagoon for studies under actual conditions. Analyses were performed for the same parameters as during methanogenic studies with the exception that in photosynthetic tests sampling was destructive.

Results

Data obtained in methanogenic studies for various waste loadings and reactor charges are summarized in Table 14, while the soluble organic COD and volatile acid levels are plotted in Figure 15. Initial soluble organic COD uptake was found to be very rapid, with the rate dependent upon initial COD level. Inhibition as evidenced by both decreased removal rate and increased volatile acid levels was noted at an added loading level of 35 lb COD/1000 cu ft (560 g/cu m). In all systems except the one showing inhibition, the rapid COD uptake was followed by a period of uniform removal which was equal in all systems. Gas production lagged behind COD uptake and was most rapid during this uniform uptake period.

Data obtained in two batch photosynthetic studies are presented in Table 15. Examination of the first study which involved incubation in unlimited light conditions indicated that photosynthetic sulfide oxidation occurred with samples from the surface and from within the lagoon depths. The oxidation progressed to sulfate at low but measurable sulfide levels as evidenced by the increase in sulfate levels in the light-incubated samples. The increase in sulfate levels would also discount

FIGURE 14
DIGESTER FOR BOTTOM SOLIDS TESTS

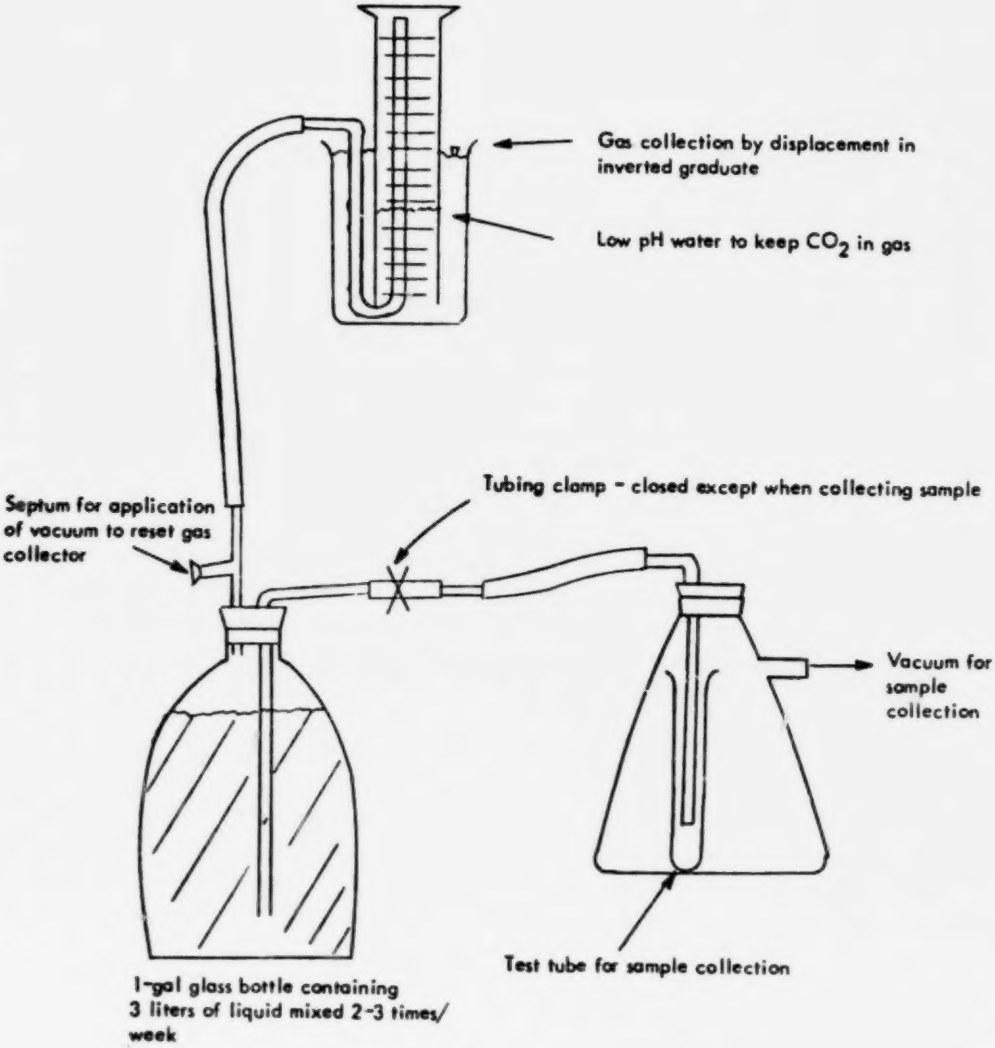

Gas collection by displacement in inverted graduate
Low pH water to keep CO_2 in gas
Septum for application of vacuum to reset gas collector
Tubing clamp - closed except when collecting sample
Vacuum for sample collection
Test tube for sample collection
1-gal glass bottle containing 3 liters of liquid mixed 2-3 times/week

TABLE 14

BATCH DECOMPOSITION IN BOTTOM SEDIMENTS

Charge Added, lb COD/1000 cu ft (a)	Day	Total (b) Organic Carbon, mg/l	Soluble (b) COD, mg/l	Soluble (c) Organic COD, mg/l	Volatile Acids, mg/l as HAc	pH	Cumulative Gas, ml	Sulfide, mg/l, $S^{=}$	Sulfate, mg/l, $SO_4^{=}$
0	0	100	330	315	72	7.5	0	5	20
	3	70	195	210	36	7.3	Nil	Nil	75
	7	70	170	160	24	7.2	20	Nil	100
	15	100	220	200	24	7.0	48	Nil	100
	33	45	180	170	12	7.5	--	Nil	175
9	0	125	470	435	24	7.3	0	5	Nil
	3	100	255	275	24	7.2	Nil	5	30
	7	80	270	210	24	7.0	62	5	20
	15	135	220	220	24	7.0	85	Nil	60
	33	75	200	200	24	7.8	--	6	80
21	0	145	670	560	120	7.5	0	5	35
	3	120	370	390	120	7.2	Nil	Nil	30
	7	95	340	280	84	6.9	108	5	Nil
	15	110	250	260	92	7.0	137	Nil	50
	33	55	225	225	24	7.8	--	26	75
31	0	215	830	750	48	7.2	0	5	25
	3	170	405	430	84	7.2	Nil	Nil	Nil
	7	100	360	290	48	7.0	138	5	Trace
	15	90	260	245	36	7.0	273	Nil	60
	33	65	245	215	12	7.7	--	6	35
35	0	250	890	755	84	7.1	0	5	100
	3	250	705	715	230	7.4	Nil	5	20
	7	200	630	565	190	6.9	121	5	Nil
	15	115	350	340	150	7.1	325	10	10
	33	80	285	290	24	7.8	--	Nil	65

Notes:

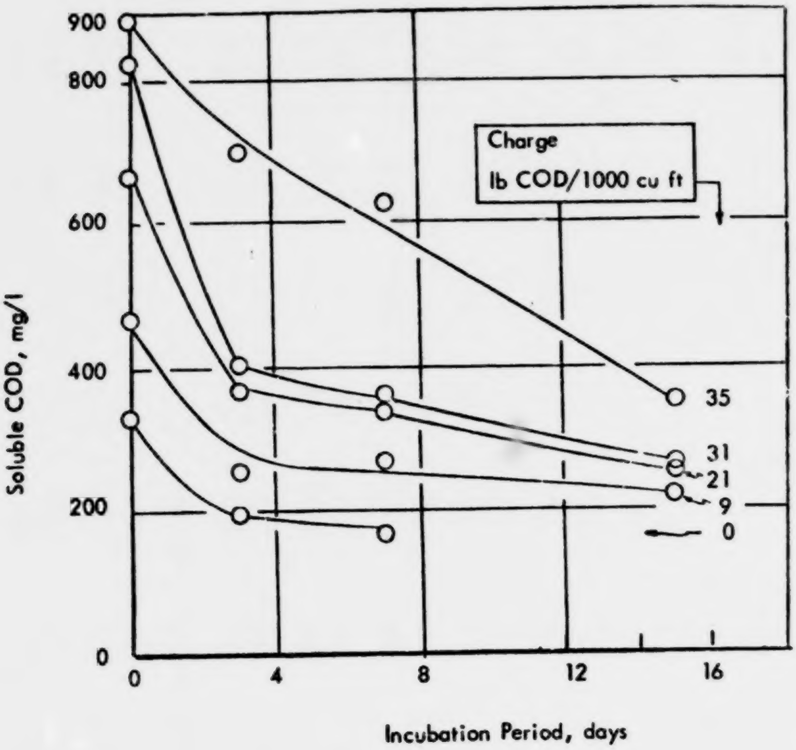
(a) All reactors contain 50% by volume lagoon bottom sludge. In addition the reactors contain dilute and concentrated wastes to provide the quoted volumetric loadings and tap water to bring the volume to 100%.

(b) Filtered.

(c) Filtered, acidified, nitrogen sparged to remove sulfides.

(d) Units were incubated at ambient temperature (25-30°C).

FIGURE 15
NON-PHOTOSYNTHETIC ANAEROBIC TESTS WITH LAGOON SLUDGE



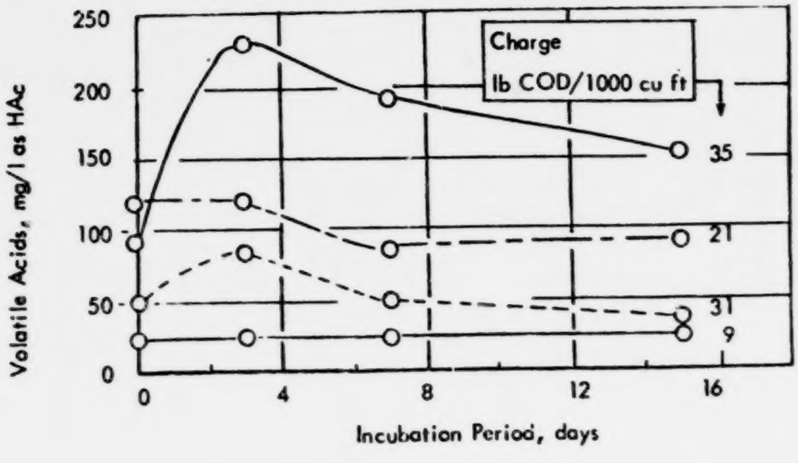


TABLE 15

BATCH PHOTOSYNTHETIC TESTS

Lagoon Seed Source	Incubation Conditions (a)	Additives	Sulfide Level, mg/l		Sulfate Level, mg/l		Soluble Organic COD (b), mg/l		Volatile Acids as HAc, mg/l	
			Initial	Final	Initial	Final	Initial	Final	Initial	Final
Study 1 - Optimum lighting, 7-day incubation in laboratory										
0.5-foot	L	None	30	9	320	355	485	370	205	36
	D	None	30	73	320	165	485	395	205	120
	L	1 g/l NaAc	30	37	320	270	1610	1440	1175	850
	D	1 g/l NaAc	30	78	320	145	1610	1630	1175	1110
3-foot	L	None	30	<5	325	310	465	360	180	24
	D	None	30	78	325	285	465	396	180	120
	L	1 g/l NaAc	30	31	325	290	1610	1400	1160	865
	D	1 g/l NaAc	30	92	325	115	1610	1590	1160	1110
6-foot	L	None	30	<5	320	375	460	340	180	36
	D	None	30	82	320	155	460	415	180	120
	L	1 g/l NaAc	30	33	320	295	1630	1340	1175	815
	D	1 g/l NaAc	30	92	320	120	1630	1630	1175	980
Study 2 - Natural lighting, 15-day incubation submerged in lagoon										
0.5-foot	L	20% waste(c)	24	15	170	110	875	435	265	60
	D	20% waste	24	72	170	Nil	875	780	265	530
3-foot	L	20% waste	25	75	155	Nil	900	690	275	370
	D	20% waste	25	70	155	Nil	900	700	275	385

(a) Both light (L) and dark (D) covered bottles were incubated at ambient temperatures (25 to 30°C).

(b) Sulfides removed by acidification and sparging with nitrogen gas.

(c) Bottle makeup 60 ml of waste (1000 mg/l COD) plus 240 ml lagoon liquor.

oxidation by molecular oxygen which would result primarily in sulfite or thiosulfate production (16). Less sulfide oxidation occurred in the presence of higher acetate levels; however, a net oxidation did occur as evidenced by the difference between the light and dark bottles. Increased COD removals and volatile acid uptakes were also observed in all lighted samples. Apparently the organisms responsible for the photosynthetic effect are present both at the surface and at a considerable depth in the lagoon.

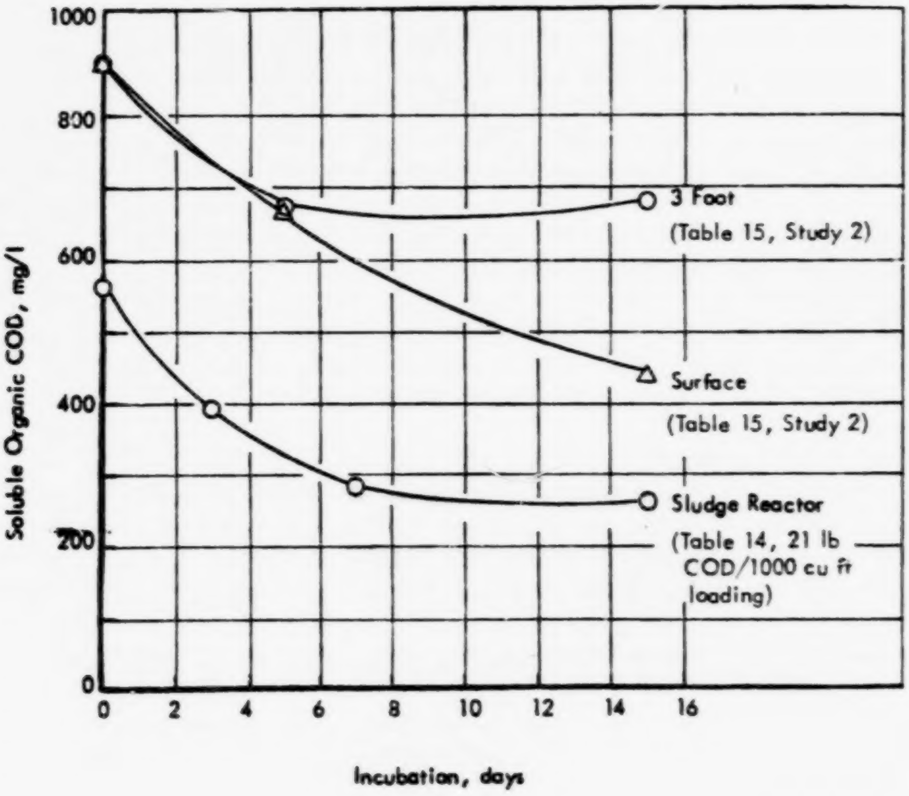
The data from the second study, in which the samples were returned to the lagoon for incubation under ambient, diurnal light and temperature conditions, indicate that near the lagoon surface the photosynthetic culture is quite active. A large uptake of both soluble organic COD and volatile acids in the diurnally lighted bottle in excess of that in the dark system is indicative of the amount of photosynthetic effect present in the surface layers. In spite of the fact that a decrease in sulfides was observed, no increase in sulfate was noted indicating either that the sulfur was stored internally or that it was potentially oxidized by a mechanism other than bacterial photosynthesis. At the three-foot depth no significant difference was noted between the lighted and dark samples. Apparently light transmission was not sufficient for photosynthetic activity at this depth. A plot of the influence of various microbial groups on the lagoon system as derived from the batch tests is illustrated in Figure 16.

The influence of depth on the contributions of the various microbial groups to overall lagoon performance may be estimated by assuming plug flow through the lagoons and no vertical mixing. If a zone of influence of two feet is assumed for the photosynthetic and sludge zones and removals in a 15-day detention time system are as evidenced in the batch tests illustrated in Figure 16, then removals of 30 and 40 percent soluble organic COD would be expected in the 12- and 6-foot (3.7 and 1.8 m) lagoons, respectively. As liquid is free to move from one area to another in an actual lagoon as shown in the tracer studies, the vertical mixing would act to temper the influence of depth on performance, particularly with the rapid initial uptake rate evidenced in the sludge layers.

The actual influence of depth was measured by both environmental profiles and performance in the two continuously fed experimental lagoons. Since the two pilot systems had identical top and bottom surface areas, an equal amount of atmospheric oxygen entrainment, photosynthetic activity, and bottom activity could be assumed. Both lagoons were also operated at the same volumetric loading rate and detention time. Differences in performance as listed in Table 8 should be directly relatable to the relative volume of the less active lagoon mid-depths.

FIGURE 16

BIOLOGICAL ACTIVITIES AT VARIOUS LAGOON DEPTHS



The experimental data indicate that at lower volumetric loading rates no significant difference in performance existed. As loading increased, the shallower lagoon provided up to a 9 percentage point increase in COD removal (17 percent increase in BOD removal). Although the magnitude of the performance difference is approximately that predicted from batch tests, the absolute COD removal is greater.

The effect of depth became pronounced when residual surface sulfide levels and profiles were examined. Averaged profile data are presented in Table 16, a typical profile in Table 17, and results of all profiles in Appendix I. The typical profile in Table 17 indicates the deeper lagoon maintained a surface sulfide level 3 to 4 times that in the shallower lagoon in the afternoon period and 4 times the shallow lagoon in the early morning. As would be expected from the batch photosynthetic studies, the sulfide profile increased from a minimum at the surface to a maximum at the sludge water interface. A tendency was also noted toward lower volatile acid and organic levels near the sludge in agreement with the rapid uptakes of these parameters observed in batch determinations. A lower concentration of total and filtered COD, total organic carbon, and volatile acids was also noted at all points in the shallower lagoon.

Averaged data for all profiles indicated that the 12-foot lagoon system maintained a surface sulfide concentration of 1.6 times that in the 6-foot lagoon (25 vs 40 mg/l) with both receiving feed sulfate levels of 400 to 500 mg/l. Effects of depth on both COD removal and sulfide concentration are summarized in Figure 17, which incorporates data from a 50-gallon reactor (2.5 foot depth) operating at a similar loading and temperature. While overall COD removal changed only 11 percentage points with a four-fold increase in depth, the surface sulfide level increased by a factor of two. The greatest increase in sulfides occurred between the 6- and 12-foot depths, while little difference was seen between 2.5- and 6-foot depths. Depth becomes important in design of a system where sulfates are present in the feed at high levels.

In practical application lagoon depth selection is tempered by soil conditions, available land area, land costs, and performance requirements as well as sulfate load. The pretreatment function of the lagoon system in waste equalization, cooling, removal of a significant portion of influent oxygen-demanding materials, and removal of inhibitory materials may be satisfied without the maximum removal possible in the system.

Operating Observations

One point which has been cited as an advantage of the lagoon system for petrochemical waste treatment is its ability to treat the rapidly varying effluent from a typical petrochemical facility with long term stability. The eleven-month operation of the demonstration lagoons provided considerable evidence of stable operation.

TABLE 16

PROFILE DATA FROM PILOT ANAEROBIC LAGOONS OF TWO DEPTHS

			Surface Sulfide, mg/l			
	Daily Mean, COD, mg/l (a)		4 a.m.		4 p.m.	
Date	12 ft	6 ft	12 ft	6 ft	12 ft	6 ft
10-1-70	656	492	56	33	51	27
10-8-70	610	507	45	33	39	31
10-29-70	570	440	68	43	59	41
1-13-71	649	585	17	0	26	11
2-17-71	607	526	19	5	17	5
3-17-71	518	420	42	34	34	31
Mean			41	25	38	24

(a) Average soluble organic COD measured at 6-16 points in lagoon at various depths.
Feet x 0.3048 = meters

TABLE 17

ANAEROBIC BASIN PROFILE

I. 4:30 p.m. 2/17/71

Parameter	Influent, Deep Basin				Effluent, Deep Basin			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.0	6.8	6.7	6.8	6.9	6.9	6.9	6.9
ORP, mv	-300	-305	-300	-300	-300	-310	-310	-290
Temp., °C	24	24	24	24	24	24	24	23
COD_T/COD_F, mg/l	685/580	690/585	700/595	655/595	635/580	675/565	630/560	670/580
TOC, mg/l	205	205	210	200	195	180	180	185
VA, mg/l as HAc	216	240	264	264	264	278	278	264
SS/VSS, mg/l	44/28	42/22	50/30	40/16	42/22	54/32	44/24	48/24
$S^=$, mg/l	15	20	23	47	19	18	16	38
SO_4, mg/l	380	375	360	290	375	380	370	300

	Influent, Shallow Basin			Effluent, Shallow Basin		
	Surface	3 ft	6 ft	Surface	3 ft	6 ft
pH	7.0	7.0	7.0	7.1	7.1	7.1
ORP, mv	-280	-280	-300	-290	-300	-310
Temp., °C	23	23	23	23	23	23
COD_T/COD_F, mg/l	635/540	620/505	615/440	615/380	615/400	640/420
TOC, mg/l	170	165	160	160	165	165
VA, mg/l as HAc	192	204	240	228	240	264
SS/VSS, mg/l	54/32	50/32	66/36	50/32	48/34	84/48
$S^=$, mg/l	5	5	29	5	5	21
SO_4, mg/l	380	410	305	380	385	290

(continued)

TABLE 17 (continued)

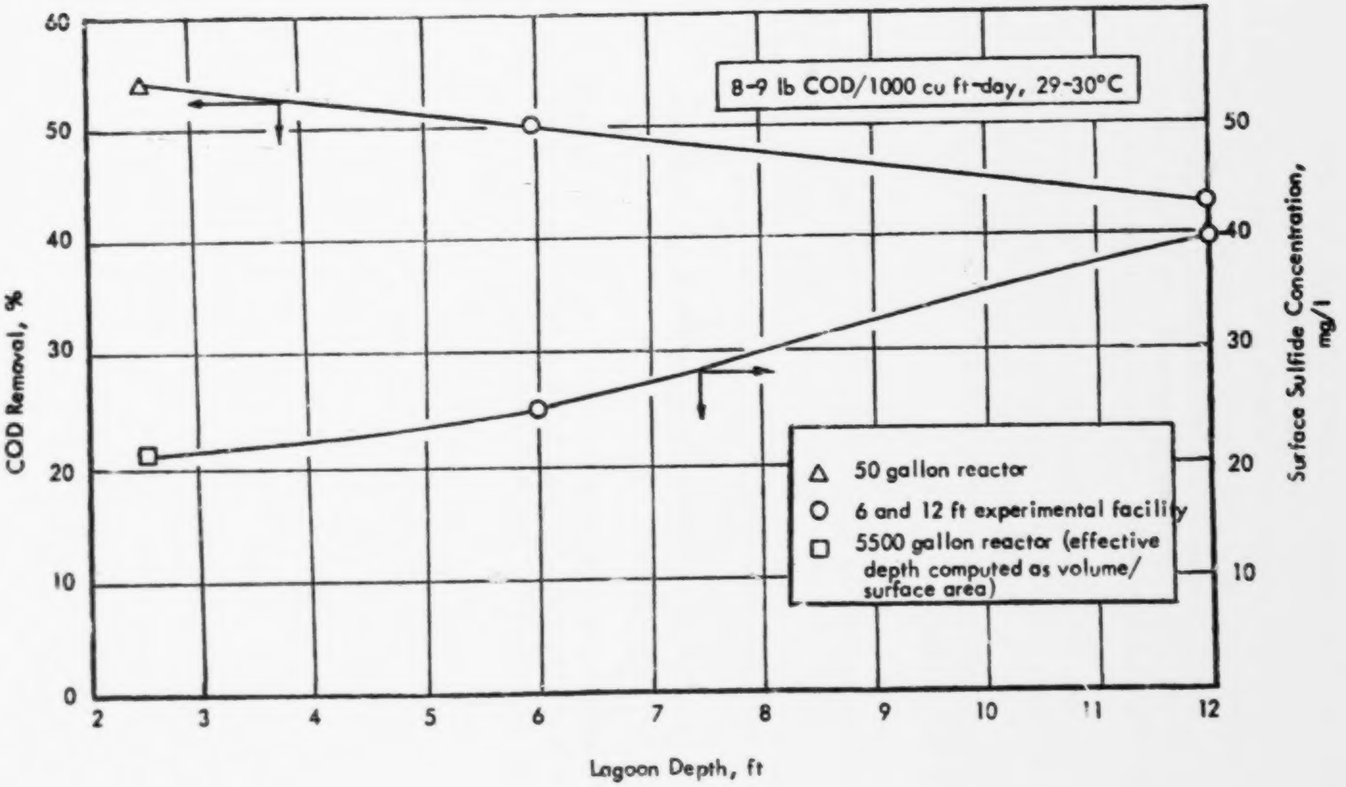
II. 4:30 a.m. 2/17/71

Parameter	North Section of I				South Section of I			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.9
ORP, mv	-310	-300	-340	-340	-310	-320	-330	-340
Temp., °C	23	21	20	20	21	21	20	19
COD_T/COD_F, mg/l	740/645	740/680	725/655	715/630	740/670	740/645	705/645	695/585
TOC, mg/l	180	170	160	195	170	210	200	205
VA, mg/l as HAc	230	230	240	192	230	278	336	264
SS/VSS, mg/l	30/22	28.24	26/21	23/18	29/21	30/25	28/20	26/20
$S^=$, mg/l	19	17	19	32	19	16	15	31
SO_4, mg/l	335	355	350	275	335	360	350	280

Parameter	North Section of II			South Section of II		
	Surface	3 ft	6 ft	Surface	3 ft	6 ft
pH	7.0	6.9	6.9	7.0	7.0	7.0
ORP, mv	-320	-300	-280	-280	-300	-320
Temp., °C	20	21	21	21	21	20
COD_T/COD_F, mg/l	645/630	680/630	655/630	690/600	665/610	690/530
TOC, mg/l	185	205	210	195	195	180
VA, mg/l as HAc	288	264	230	216	230	264
SS/VSS, mg/l	35/26	38/32	37/32	38/31	37/29	104/61
$S^=$, mg/l	5	5	5	5	8	19
SO_4, mg/l	370	370	365	360	375	330

FIGURE 17

EFFECT OF LAGOON DEPTH ON COD REMOVAL AND SULFIDE LEVEL



Examination of the influent-effluent COD graphs (Appendix I) indicated that many times during the course of operation the influent COD levels would at least double. As the feed samples analyzed were composite samples over a 3-day period, the instantaneous levels were undoubtedly much greater in the on line system without equalization. In no case did the influent variation cause problems in lagoon operation. With the exception of one spill, the influent peaks were diluted and subsequently degraded without an increase in effluent level.

Due to failure of the feed pH control equipment, the lagoon was also subjected to many pH shocks. Examples of maximum and minimum levels experienced are indicated in Table 18. Obviously the lagoon is very insensitive to short duration (5 to 6 days) of acid feed (4 to 5) or to shorter periods (3 days) of basic feed (9 to 9.5).

One reason for the ability of the lagoon to withstand an acid feed is the presence of volatile acid salts in the influent. Biological decomposition of the volatile acid segment releases undissociated cations which result in increasing system alkalinity. For example, an overall reaction for decomposition of sodium acetate yields an increase in biocarbonate alkalinity as

$$CH_3COONa + H_2O \longrightarrow CH_4 + NaHCO_3$$

This phenomena was so prevalent in the demonstration lagoons that a lagoon feed pH of 6.5 to 7.0 resulted in lagoon pH range of 7 to 8. In all cases (Table 8) an increase in pH through the lagoons was noted.

TABLE 18

pH SHOCKS IN FEED TO ANAEROBIC LAGOON

Date	pH (a)	Duration, days	Resulting Effect in Lagoon
September 2, 1970	8.8	1	None
7	2.3	1	None
9	2.1	1	None
January 10, 1971	5.1	3	None
11	5.6		
12	5.2		
February 8, 1971	3.8	1	Slight pH dip, immediate recovery
28	3.0	1	None
March 8, 1971	9.5	3	None
9	9.2		
10	9.0		
28	4.5	5	None
29	4.6		
30	4.6		
31	5.2		
April 1, 1971	4.9		
7	5.2	6	None
8	4.8		
9	5.2		
10	4.8		
11	4.8		
12	4.2		
May 1, 1971	4.8	5	None
2	5.6		
3	4.4		
4	2.7		
5	5.2		
16	5.0	12	Lagoon 1 pH dropped from pH 7.5 before low pH feed to 6.2 on May 23rd, recovered on 25th with no effects
17	2.4		
18	5.0		
19	5.8		
20	4.3		
21	5.3		
22	3.1		
23	5.9		
24	9.1		
25	5.8		
26	4.5		
27	5.6		

SECTION VI

AERATED STABILIZATION OF ANAEROBIC EFFLUENT

In order to provide the additional treatment required prior to release of an anaerobic effluent to the environment, an aerated stabilization process was selected for the demonstration-scale study. Aerated stabilization was chosen due to a previously reported problem (3) in maintaining a flocculent bacterial population in a conventional, complete-mix activated sludge system with the varying winter-summer feeds from an anaerobic lagoon.

The aerated-stabilization process calls for less critical operation and can accept varying applied loads since it does not rely on maintenance of conditions required by the sensitive floc-forming bacteria. The aerated stabilization system was followed by two facultative lagoons primarily for solids removal, storage, and decomposition.

The aerated stabilization process is a high-rate lagooning operation employing a low concentration of non-flocculent bacteria which are synthesized during bio-oxidation of the organics and are discharged with the effluent. Given a proper environment and lack of toxicants, the performance of an aerated stabilization process is limited by one of two factors. If the system is not operated at a positive oxygen level, then removal is dependent upon the quantity of oxygen supplied. If oxygen is maintained above some level where performance is independent of oxygen concentration, then retention time for bacterial growth and resulting assimilation of waste products is the limiting mechanism. If the rate of liquid flow through the reactor and resulting detention time is less than the time required for stabilization, only a portion of the waste will be removed. As the detention time becomes large, near equilibrium stabilization is reached. Based on previous studies performed by Union Carbide (3) a retention time of three days was selected for the demonstration aerated stabilization study.

Performance

Data obtained as grouped for temperature, loading, and other test conditions are presented in Table 19, while performance and daily operating data are presented in Table 20 and Appendix I, respectively.

In addition to normal temperature and loading variations, a study of controlled dissolved oxygen levels was made. Also, additional more-concentrated wastes were added to both the anaerobic and aerobic units to increase the loading level.

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TABLE 19

AERATED STABILIZATION ANALYTICAL SUMMARY

Date	Feed*									Effluent											Notes
	pH	Temp.	COD_T	COD_F	TSS	VSS	BOD	VA	Alk	pH	Temp.	DO	COD_T	COD_F	TSS	VSS	BOD_T	BOD_F	Alk	
10-1 to 11-3-70	7.4	26	528	349	102	75	148	261	557	7.6	22	4.1	264	184	54	42	44	--	474	--
11-4 to 11-22-70	7.4	21	496	396	83	54	130	215	483	7.6	17	1.0	444	306	138	87	95	--	448	Low DO
11-23 to 12-17-70	7.2	20	659	581	78	40	224	60	413	7.7	19	4.9	383	266	138	95	74	69	344	--
12-18-70 to 1-3-71	8.1	21	731	--	--	--	216	--	686	7.8	19	4.5	445	306	222	155	72	--	528	--
1-4 to 1-11-71	8.1	14	730	--	--	--	283	--	728	8.4	10	5.4	557	444	184	121	145	90	578	--
1-12 to 2-4-71	8.2	20	828	--	--	--	325	--	696	7.8	17	4.2	428	230	220	169	94	64	386	--
2-5 to 2-15-71	7.0	16	648	610	57	43	216	180	438	7.7	13	7.4	374	181	198	161	59	26	264	--
2-16 to 3-9-71	7.0	18	672	614	58	39	196	247	380	7.2	17	4.7	343	234	174	134	53	28	210	--
3-10 to 4-14-71	7.2	21	727	660	55	43	287	236	597	7.6	19	3.8	430	267	156	134	85	33	414	--
4-15 to 5-27-71	7.2	25	991	890	67	54	386	386	793	8.0	23	4.1	522	246	283	246	104	30	583	--
5-28 to 6-30-71	7.1	29	1070	991	86	61	582	659	903	7.2	26	4.1	488	275	254	212	95	37	609	--

* Note - Will in some cases be the same as anaerobic lagoon effluent

Units are as expressed in Table 7.

TABLE 20

AERATED STABILIZATION PERFORMANCE SUMMARY

Date	Loading, lb/1000 cu ft-day		Percent Removal				Oxygen Uptake mg/l-hr	Oxygen Required lb Oxygen/lb BOD_R
	BOD	COD	BOD_T	BOD_F	COD_T	COD_F		
10-1 to 11-3-70	3.1	10.9	70	--	50	47	--	--
11-4 to 11-22-70	2.7	10.3	27	--	10	23	Low DO	--
11-23 to 12-17-70	4.7	13.7	67	69	42	54	--	--
12-18 to 1-3-71	4.5	15.2	67	--	39	--	--	--
1-4 to 1-11-71	5.9	15.2	49	68	24	--	--	--
1-12 to 2-4-71	6.8	17.2	71	80	48	--	--	--
2-5 to 2-15-71	4.5	13.5	73	88	42	70	3.7	1.5
2-16 to 3-9-71	4.1	14.0	73	86	49	62	2.8	1.5
3-10 to 4-14-71	6.0	15.1	70	89	41	60	6.9	2.6
4-15 to 5-27-71	8.0	20.6	73	92	47	72	8.6	2.3
5-28 to 6-30-71	12.1	22.2	84	94	54	72	8.4	1.3

In order to determine the limiting oxygen level an 18-day study was performed (November 4 to November 22, 1970) in which the oxygen level was controlled at a 1 mg/l concentration. During the prior and subsequent operation periods the over-sized aerator was not controlled and the oxygen level was generally at a 4 mg/l level or above. During the controlled period the aerated stabilization basin became dark and odorous. A large decrease in removal of total BOD and total and filtered COD was also noted. Such a performance decrease was unexpected with 1 mg/l residual DO as many aerated stabilization units operate successfully with no measurable oxygen residual although they may suffer some performance decrease. The presence of a dissolved oxygen residual was verified by using both the Winkler titration and a polarographic probe, so the basin was by definition "aerobic" in spite of odors. Determinations made during this period also indicated nil soluble sulfides and a low level of reduced iron present in the system which would contribute to the high residual BOD and COD.

Chen and Morris (16) have indicated the oxidation of sulfide by molecular oxygen to be a complex series of reactions with rate and end products dependent upon sulfide level, oxygen level, and catalysts present. Conceivably, the lower oxygen level present during the low oxygen study could result in incomplete conversion of sulfides and a resulting end product such as sulfite, thiosulfate or elemental sulfur detectable in the BOD and COD tests. Each of these compounds were analyzed in the COD determination at concentrations of 1000 mg/l to determine whether it would result in a significant oxygen demand as measured by the COD technique. Results indicated that while elemental sulfur was insoluble and only slightly oxidized, sulfide and thiosulfate were 87 and 77 percent oxidized, respectively. The presence of partially oxidized sulfur forms rather than incomplete carbon removal could have contributed to the performance decrease.

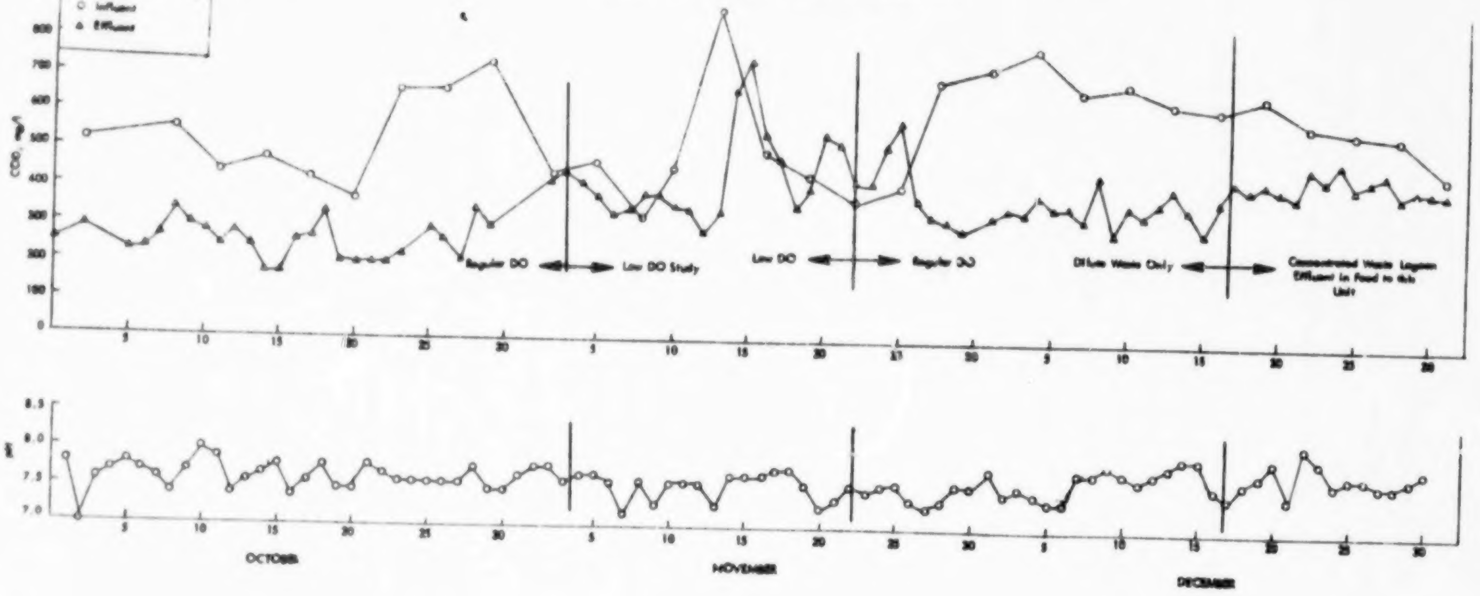
Overall oxygen requirements were determined by monitoring the oxygen level with time in a 300-ml BOD bottle filled with the system mixed liquor. Due to the stressed conditions which existed periodically in the aeration basin, a definite correlation of oxygen requirements was difficult. The data do indicate that conceivably more than one pound of oxygen per pound of BOD removed was required.

The oxygen level was raised (11/23/70 - 12/16/70) following the low oxygen test, at which point BOD removal increased to the 67 percent level confirming that oxygen level was the controlling factor. Operating observations indicated that a DO residual of 1.5 mg/l was necessary to avoid problems.

During the period of December 18, 1970 to February 4, 1971, effluent from an anaerobic lagoon treating concentrated waste was added to the aerated stabilization feed to provide a higher organic feed level and to determine whether a concentrated waste could undergo further stabilization after long-term (approximately one year) anaerobic lagooning. The initial study period (December 18 to January 3) indicated

FIGURE 18

AERATED STABILIZATION DATA, OCTOBER-DECEMBER, 1970



no operational problems and organic removals comparable to performance without the additional feed. However, between January 4 and 11, a brief cold snap and a high pH resulting from the alkaline concentrated anaerobic waste resulted in decreased BOD and COD removals. Addition of sulfuric acid to the aeration basin provided an increase in removals to previous levels.

Between April 15 and June 30, 1971, a concentrated waste was added to the anaerobic lagoon to bring the overall waste strength to 1000 mg/l BOD. The increased loading to the anaerobic system resulted in a higher loading to the aerobic lagoon. As discussed in the anaerobic lagooning section, a high system pH (8.0) accompanied decomposition of the waste high in salts of volatile acids. Inhibition was indicated at this pH as evidenced by both decreased oxygen uptake and high organic residual during peak loadings as may be seen in examination of Figures 18-20. From the oxygen uptake data inhibition apparently occurs at pH levels greater than about 8.0. Neutralization with sulfuric acid (May 28 to June 30, 1971) restored system performance to normal.

Loading and Retention-Time Effects

The percentage of organic material removed in aerated stabilization has been found to be dependent upon the influent organic concentration. Because the efficiency of the prior anaerobic lagooning step is temperature dependent, the aerated-stabilization process will receive a varying load. Performance in the aerated-stabilization process at various influent loads must be evaluated to predict the effluent quality. A previously developed (3) BOD removal loading curve for a 3-day aeration time together with the removal data collected in this study are presented in Figure 21. Removals of BOD are near equal to or better than those reported in small-scale studies except for periods of imposed stress (high pH or low DO).

Examination of the performance-loading curves indicates that BOD removal is a function of volumetric loading (lb BOD/1000 ft^3-day) for the three-day detention time. The increase in reduction efficiency with loading is in agreement with the theory of complete-mix, continuous-culture systems which predict an effluent concentration of the limiting substrate which is independent of influent concentration under steady-state conditions. At higher loadings, a greater efficiency removal would then be obtained as influent concentration increased and effluent concentration remained approximately constant. A difference in removal of approximately 10 percent was noted between winter and summer operation. The absolute difference could be due to temperature influence on the predominant biological culture or to different products in the anaerobic lagoon effluent. For example, the anaerobic system could produce a more stabilized waste in the summer periods with less contained volatile acids and a more complete breakdown of complex influent wastes.

FIGURE 19

AERATED STABILIZATION DATA, JANUARY-MARCH, 1971

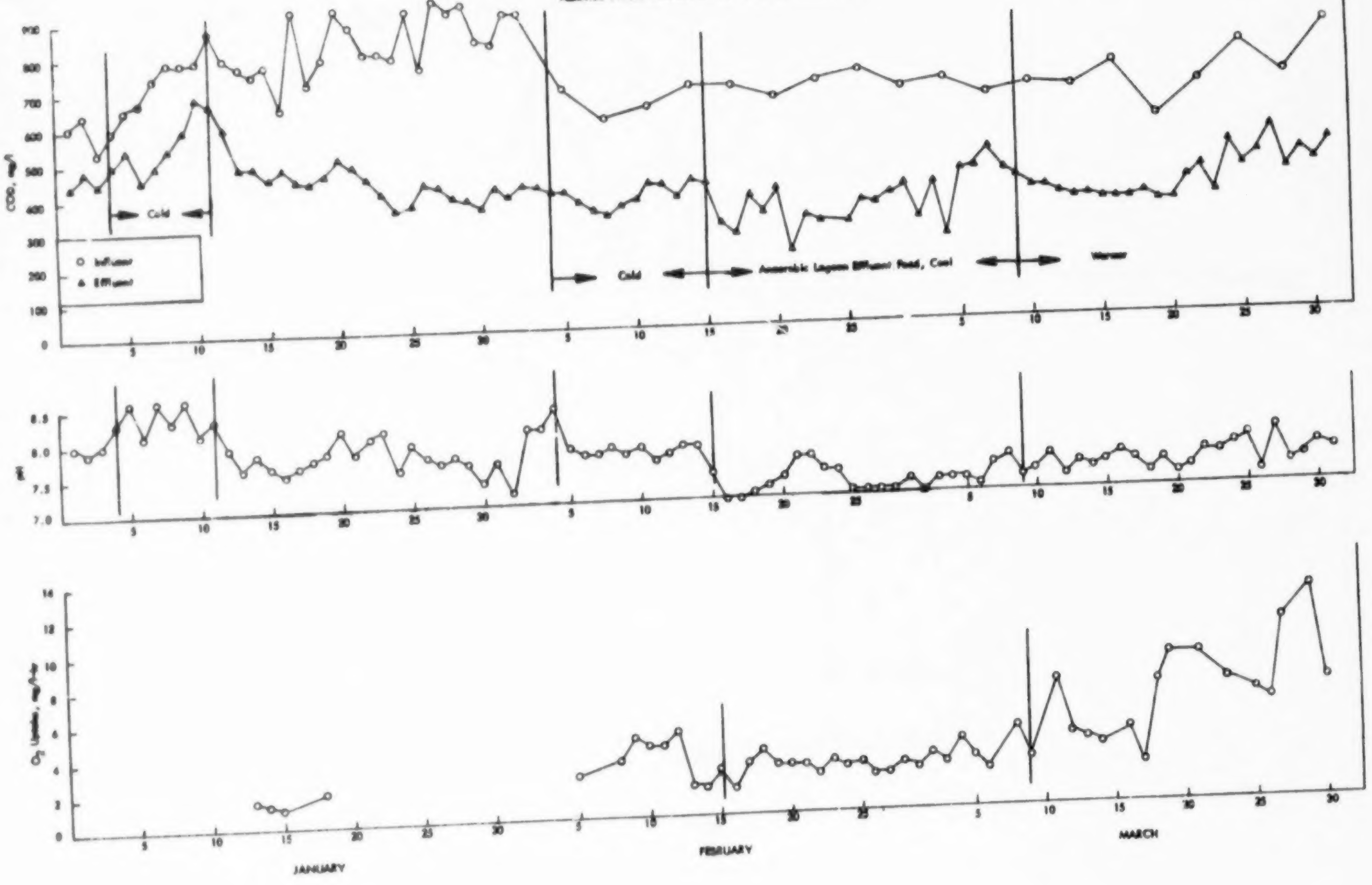


FIGURE 20
AERATED STABILIZATION DATA, APRIL-JUNE, 1971

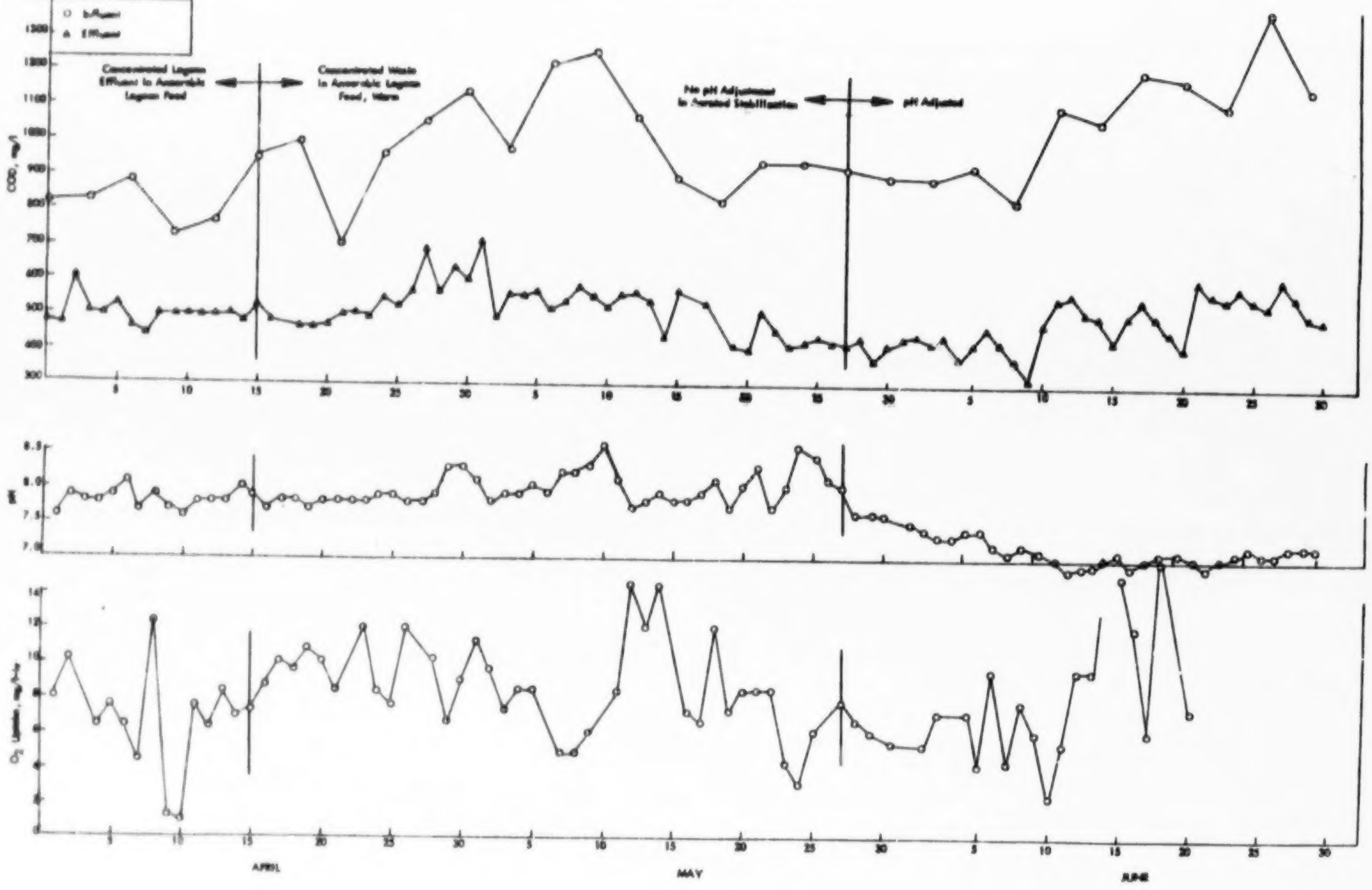
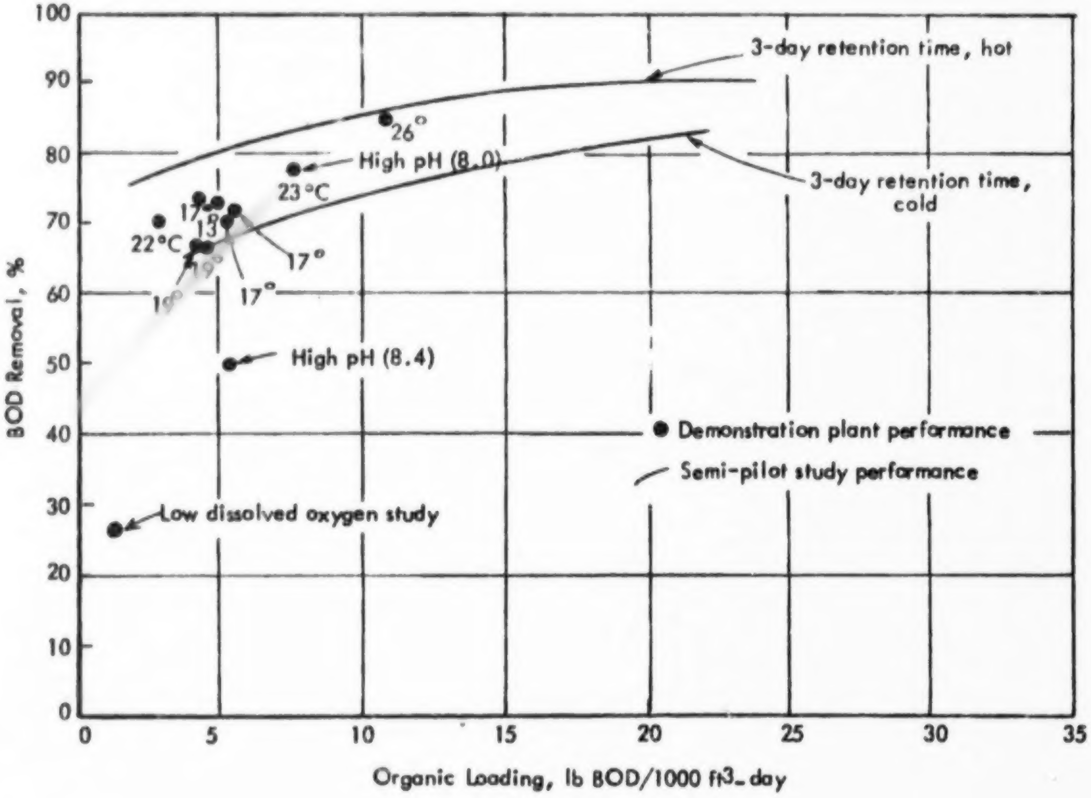


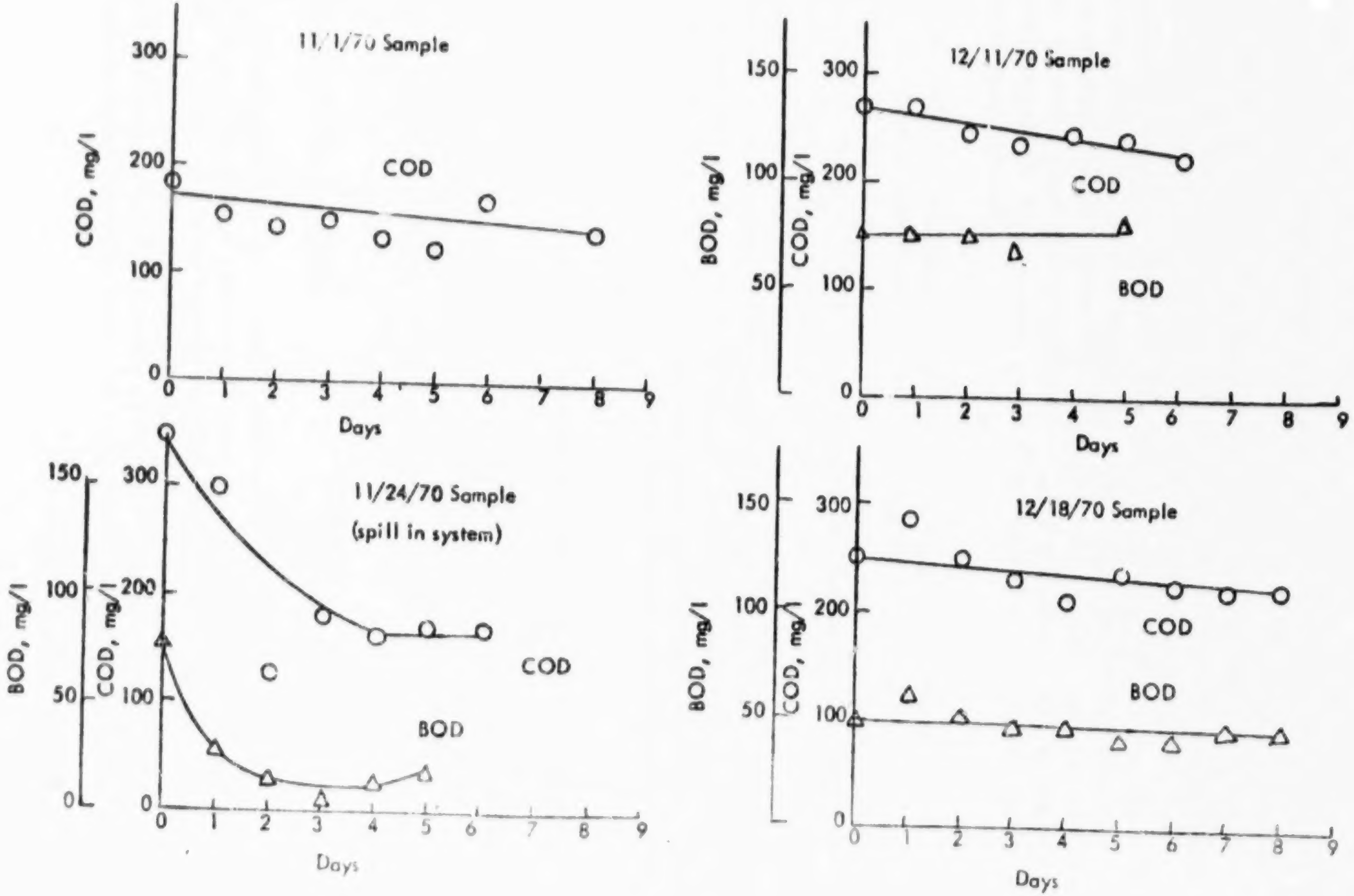
FIGURE 21

AERATED-STABILIZATION TREATMENT OF ANAEROBIC EFFLUENT
PERFORMANCE WITH RESPECT TO PREVIOUS SEMI-PILOT STUDIES



To confirm that a 3-day aeration period was sufficient for virtually complete degradation, samples were taken from an aerated stabilization system operating at a 3-day detention and aerated in a batch degradation test under ambient conditions for up to 8 additional days. Samples were obtained daily from this batch test. The results presented in Figure 22 indicate no additional degradation with longer aeration periods using samples collected under non-upset conditions.

FIGURE 22
EFFECT OF ADDITIONAL AERATION ON AERATED STABILIZATION EFFLUENT



SECTION VII

FACULTATIVE LAGOONS

In many instances the effluent from the aerated-stabilization process needs to be clarified before release to receiving waters as these biological solids can contribute 0.2 to 0.5 lb BOD_5/lb solids released. Because the produced biosolids are non-flocculent and consequently settle at a slow rate, a conventional clarifier may be inefficient in removal. Facultative lagoons were selected in the demonstration facility to provide a long retention time and large area for solids separation and for subsequent storage and anaerobic decomposition of the solids. Two lagoons in series were designed for the demonstration facility, each of a six-foot depth and providing two days' retention.

Operating and BOD-removal data for the facultative lagoons are presented in Table 21. The lagoons were able to provide a total BOD removal of 40 to 50 percent except for the period of low dissolved oxygen in the prior aerated stabilization unit. The removal was primarily through solids sedimentation as evidenced by the relatively low soluble BOD reductions. A system effluent of less than 50 mg/l total BOD was noted except during stressed periods of aerated-stabilization operation. The performance of the lagoons in solids removal is summarized in Figure 23. The best fit line indicates a net "removal" of approximately 60 percent of the applied volatile and suspended solids. The removal was expressed on a net basis as the primary constituent in the effluent was visually noted to be produced algae while the influent contained primarily bacteria.

A profile of environmental parameters within the facultative lagoons is reported in Table 22. A dissolved oxygen residual is noted at all points with the maximum concentration at the effluent. Minor sulfide concentrations also were noted and are indicated by the low oxidation reduction potential in spite of the oxygen present. Only a slight suspended solids gradient is seen through the lagoons indicating that on this date the influent suspended solids (period average 150 mg/l) were rapidly settled.

Sludge Storage and Decomposition

In order to evaluate the facultative lagoons as a means of solids storage and decomposition a solids material balance was made around the system after operation had ceased. To determine the solids accumulated, samples of the lagoon contents were collected by lowering a piece of glass tubing to the bottom of the lagoon. The top was then stoppered and the tubing withdrawn. The bottom of the tube was stoppered before lifting above the surface of the water. The tubing containing the

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TABLE 21

FACULTATIVE LAGOON SUMMARY

	Feed*									Number 1 Effluent						Number 2 Effluent								Removals	
Date	pH	Temp.	COD_T	COD_F	TSS	VSS	BOD_T	BOD_F	Alk	pH	COD_T	COD_F	TSS	VSS	Alk	pH	COD_T	COD_F	TSS	VSS	BOD_T	BOD_F	Alk	BOD_T	BOD_F
11-2 to 11-22-70	7.6	17	444	306	138	87	95	51	448	7.5	371	263	79	60	479	7.7	322	215	61	38	36	29	--	62	--
11-23 to 12-17-70	7.7	19	383	266	138	95	74	69	344	7.5	354	250	94	67	355	7.6	327	243	89	55	70	--	338	5	--
12-18-70 to 1-3-71	7.8	19	445	306	222	155	72	--	528	7.8	382	290	121	89	498	7.9	330	265	100	69	45	--	489	38	--
1-4 to 1-11-71	8.4	10	557	444	184	121	145	90	578	8.0	437	368	141	100	548	8.0	403	335	123	92	67	--	559	54	--
1-12 to 2-4-71	7.8	17	428	230	220	169	94	64	386	7.8	307	255	102	70	404	7.8	302	236	85	58	46	--	442	51	--
2-5 to 2-15-71	7.7	13	374	181	198	161	59	26	264	7.5	248	172	90	72	338	7.6	225	180	75	55	31	22	354	48	15
2-16 to 3-9-71	7.2	17	343	234	174	134	53	28	210	7.1	280	223	70	55	209	7.3	242	195	55	39	32	20	217	40	20
3-10 to 4-14-71	7.6	19	430	267	156	134	85	33	414	7.5	343	254	72	59	418	7.5	289	247	49	36	49	24	410	43	27
4-15 to 5-27-71	8.0	23	522	246	283	246	104	30	583	7.8	409	266	148	132	609	7.9	354	259	117	102	55	25	628	47	16
5-28 to 6-30-71	7.2	26	488	275	254	212	95	37	609	7.7	361	303	102	83	724	7.8	320	264	86	70	49	28	753	48	24

* Aerated stabilization effluent was feed to No. 1 Lagoon, which in turn fed into No. 2 Lagoon.
Units are as expressed in Table 7.

FIGURE 23

RELATIONSHIP OF LAGOON FEED AND EFFLUENT SOLIDS LEVELS

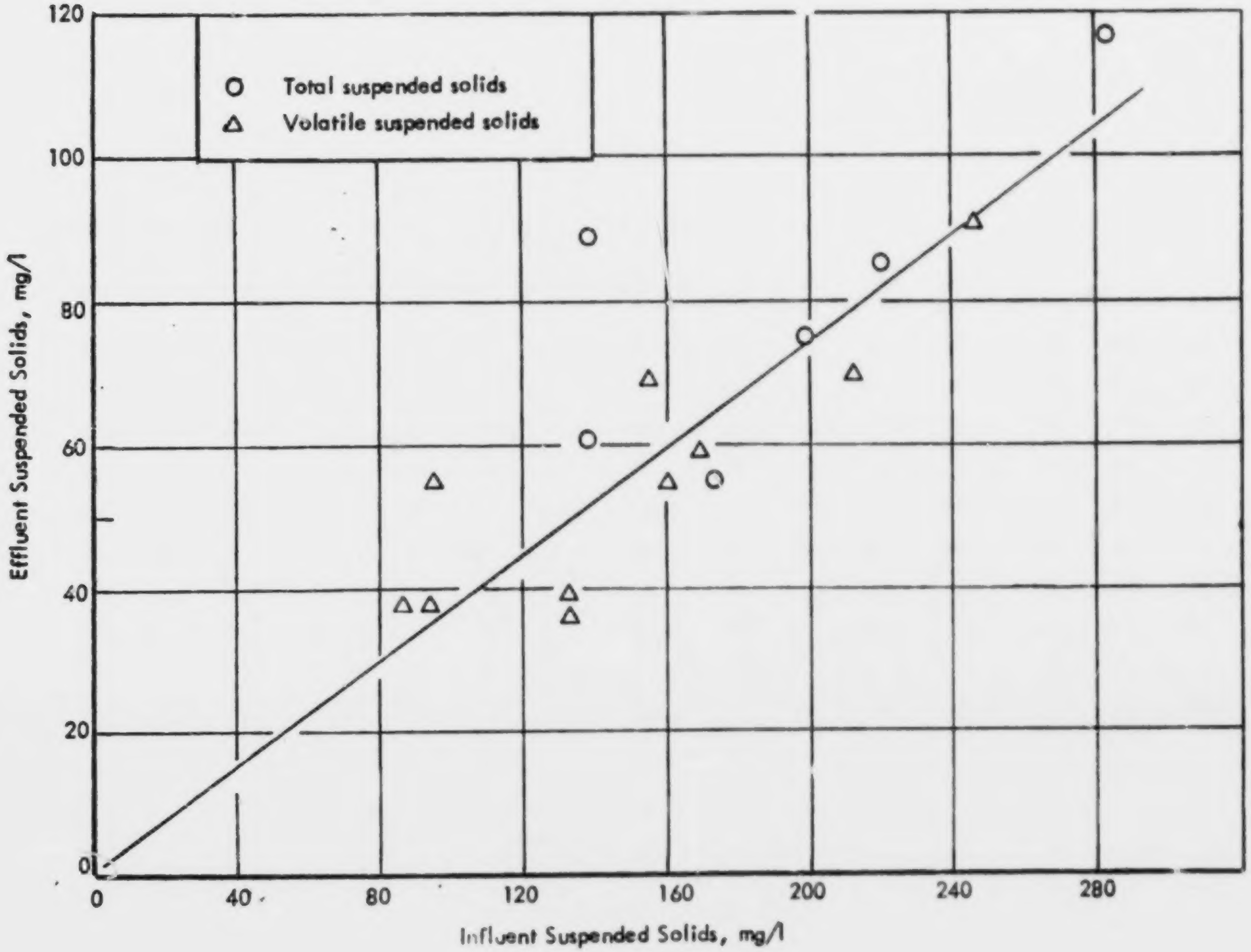

TABLE 22

PROFILES OF FACULTATIVE LAGOONS I AND II

	North Section I				South Section I				South Section II				North Section II			
	Surface	3 Ft	6 Ft	Sludge	Surface	3 Ft	6 Ft	Sludge	Surface	3 Ft	6 Ft	Sludge	Surface	3 Ft	6 Ft	Sludge
12 Noon 3-9-71																
pH	7.0	6.9	6.9	6.6	7.0	7.0	6.4	6.7	7.3	7.2	7.2	6.8	7.2	7.2	7.1	6.9
ORP, mv	-160	-260	-260	-300	-190	-230	-320	-340	-120	-220	-230	-300	-200	-260	-270	-290
Temp., °C	15	15	14	13	15	15	13	14	16	17	12	13	16	15	18	13
DO, mg/l	2.4	0.3	0.2	0.2	0.6	0.3	0.2	0.2	3.8	1.8	1.6	2.4	0.6	0.3	0.4	0.3
COD, mg/l	270	270	280	255	275	270	375	265	225	230	230	190	230	225	235	235
TSS/VSS, mg/l	72/56	70/56	68/50	78/63	70/56	76/58	76/60	83/72	68/52	64/48	64/46	78/62	64/48	60/46	68/52	74/62
Sulfide, mg/l	5	6	10	19	5	9	8	17	6	8	9	80	19	15	18	45
SO_4, mg/l	600	600	590	560	595	615	615	610	630	655	630	245	600	610	590	430

Notes: Flow is from North I ——→ South I ——→ South II ——→ North II sample was lowered into a dry ice-acetone mixture, frozen, and cut into 6-inch sections. The sections were thawed completely prior to performing the analyses indicated in Table 23.

Based on the solids monitoring data for the influent and effluent (Table 21), 2347 pounds of total suspended solids and 1938 pounds of volatile suspended solids were removed during the 231-day operational period. Solids remaining in the lagoon system were composed of 1030 pounds total suspended solids and 585 pounds volatile suspended solids. A material balance proved that degradation of total and volatile suspended solids amounted to 50 and 70 percent, respectively. A change in volatility from 82 percent to 56 percent was observed with the decomposition. The maximum final sludge composition observed was 3.7 percent total suspended solids.

Useful life of the lagoon system can be estimated as follows. If a 4-foot allowable sludge depth, a 4 percent final sludge concentration, a 240 mg/l TSS influent, and removal and degradation as existed in the demonstration system are assumed, then the two 2-day lagoons would have a useful life of 4.6 years before cleaning.

TABLE 23

FACULTATIVE LAGOON SLUDGE PROFILE

	Organic Soluble COD, mg/l	TSS, mg/l	VSS, mg/l	VA, mg/l as HAc	pH
Basin #1 Influent Area					
Bottom 6" Section	1,470	22,900	13,800	72	7.5
2nd 6" Section from Bottom	1,220	21,800	13,700	96	7.3
3rd 6" Section	1,080	13,700	8,140	192	7.4
1" Above Sludge Level	430	140	60	84	7.7
Basin #1 Effluent Area					
Bottom 6" Section	930	25,510	17,000	132	7.2
2nd 6" Section from Bottom	880	19,600	11,400	144	7.3
1' Above Sludge Level	210	72	52	60	8.0
Basin #2 Influent Area					
Bottom 6" Section	380	6,640	3,510	72	7.7
1" Above Sludge Level	255	68	44	72	8.1
Basin #2 Effluent Area					
Bottom 6" Section	795	37,400	16,000	192	7.5
1' Above Sludge Level	245	72	44	48	8.0

SECTION VIII

OVERALL SYSTEM PERFORMANCE AND SPECIAL STUDIES

Overall system performance in terms of BOD and COD removal is presented in Table 24. Except during the period of the low oxygen study in the aerated stabilization system, the series system consistently provided a total BOD removal of greater than 90 percent and a soluble BOD removal of 95 percent or greater. A total COD removal of 75 to 81 percent was observed during this period. Twelve analyses of the aerated stabilization and facultative lagoon effluents by gas chromatography indicated that none of the identifiable components entering the treatment system were present in identifiable quantity in the effluent from either of these processes. The treatment system operated on-line during the entire study except for equipment problems. As mentioned under the anaerobic lagoon section, the ability of the lagoons to absorb both organic and pH shocks and to provide a long term BOD removal of greater than 90 percent served to demonstrate system reliability.

In order to estimate nutrient requirements and to determine the fate of nutrients in the anaerobic-aerobic system, analyses were selected or developed for testing samples collected at various points in the system. It was necessary to develop ammonia and phosphate methods applicable to anaerobic systems and to systems containing amine wastes. The methods used are included as a part of Appendix II, while data obtained are listed in Table 25. Nitrate data indicate that little nitrate ion enters the treatment system and that no nitrification occurs in the aerated stabilization process.

Ammonia and phosphorous data are inconclusive, apparently indicating only the variable influent content in the wastes. Little definable uptake through the biological system was noted.

Long term (20-day) BOD concentrations also were determined in special studies on the demonstration-scale facility. Data are presented in Table 26 which includes a ratio of 5-day to 20-day BOD. A comparison of 20-day BOD, 5-day BOD, and COD removals are listed in Table 27.

The BOD$_5$/BOD$_{20}$ ratio could be considered indicative of the relative ease of degradation of a waste, assuming a seed equally acclimated to all compounds. An easily or a rapidly degraded waste would have a ratio near one, while a slowly degraded waste should have a ratio considerably less than one. In passing through a treatment process a heterogeneous waste would be expected to have a decreasing ratio if the easily degraded compounds were preferentially removed. If all

TABLE 24

OVERALL SYSTEM PERFORMANCE

Date	Influent, mg/l		Effluent, mg/l		Removal, %			Notes
	BOD	COD	BOD	COD	BOD_T	BOD_F	COD	
11-3-70 to 2-7-71	478	986	52	328	89	--	67	Includes period of low oxygen study in aerated stabilization basin
2-8-71 to 3-10-71	417	967	32/20	237	92	95	75	--
3-11-71 to 4-14-71	550	1138	48/24	289	91	96	75	--
4-15-71 to 6-30-71	881	1786	52/26	339	94	97	81	Increased influent concentration period

Note - Units are as expressed in Table 7.

TABLE 25

NUTRIENT ANALYSES

Nutrient (a)	System (b) Influent	Anaerobic-Lagoon Effluent Number 1	Anaerobic-Lagoon Effluent Number 2	Aerated Stabilization Effluent	Facultative Lagoon Effluent
January 21, 1971					
NO_3	0.2	0.25	0.3	0.7	0.3
Ortho-PO_4 (c)	45.8	45.2	45.8	49.4	35.5
Total Hydrolyzable Phosphate (TH-PO_4)	56.6	64.5	50.8	58.7	45.2
March 17-19, 1971					
NO_3	0.3	0.1	0.3	--	0.2
NH_3 (d)	247.0	100.0	74.0	--	68.0
Ortho-PO_4	41.0	20.0	38.0	--	42.0
TH-PO_4	--	72.0	--	--	--
March 20-22, 1971					
NO_3	0.3	0.1	0.2	0.2	0.2
NH_3	62.0	65.0	64.0	49.0	22.0
Ortho-PO_4	25.0	32.0	22.0	36.0	36.0
TH-PO_4	60.0	107.0	65.0	53.0	55.0
April 24-26, 1971					
NH_3	254.0	212.0	167.0	94.0	144.0
April 27-29, 1971					
NH_3	75.0	171.0	131.0	51.0	106.0
June 14, 1971					
NO_3	0.3	0.3	0.3	0.3	0.2
NH_3	39.0	34.0	25.0	26.0	22.0
Ortho-PO_4	44.0	69.0	67.0	44.7	77.0

(a) Concentration of nitrate ions and ammonia are mg/l or N, phosphorous forms are as phosphate

(b) 3-day composite sample

(c) 40 mg/l H_3PO_4 added as nutrient

(d) 45 mg/l NH_3 added as nutrient

TABLE 26

LONG TERM BOD DATA

20-day BOD, mg/l

Date	Anaerobic Lagoon Influent	Anaerobic Lagoon No. 1 Effluent	Anaerobic Lagoon No. 2 Effluent	Aerated Stabilization Effluent	Facultative Lagoon Effluent
9/18/70	--	--	--	56 (0.45)	--
9/19/70	--	--	--	--	--
9/20/70	698 (0.96) (a)	104 (1.50)	135 (1.11)	28 (0.71)	--
9/21/70	--	--	--	--	--
9/22/70	--	--	--	69 (0.74)	--
9/23/70	460 (0.98)	133 (0.87)	153 (0.86)	48 (0.79)	--
9/24/70	--	--	--	56 (0.79)	--
9/25/70	--	--	--	--	--
9/26/70	726 (0.87)	135 (1.07)	115 (0.99)	52 (0.65)	--
9/27/70	--	--	--	34 (0.74)	--
9/28/70	626 (0.84)	178 (0.94)	206 (0.95)	58 (0.79)	--
9/29/70	--	--	--	72 (1.19)	--
9/30/70	--	--	--	106 (0.60)	--
10/1/70	--	--	--	74 (0.93)	--
10/2/70	598 (0.97)	158 (0.77)	202 (0.97)	68 (0.93)	--
10/3/70	--	--	--	52 (0.44)	--
10/4/70	--	--	--	44 (0.59)	--
10/5/70	375 (1.17)	140 (1.31)	144 (0.96)	35 (0.51)	--
10/6/70	--	--	--	34 (0.47)	--
10/7/70	--	--	--	52 (0.81)	65
10/8/70	--	--	--	58 (0.98)	--
10/9/70	--	--	--	54 (0.67)	--
10/10/70	--	--	--	32 (0.88)	--
10/11/70	518 (0.97)	144 (0.97)	158 (1.01)	42 (0.71)	--
10/12/70	--	--	--	44 (0.61)	--
10/13/70	--	--	--	27 (0.96)	--
10/14/70	--	--	--	29 (0.79)	--

(continued)

TABLE 26

LONG TERM BOD DATA

20-day BOD, mg/l

Date	Anaerobic Lagoon			Aerated Stabilization Effluent	Facultative Lagoon Effluent
	Influent	No. 1 Effluent	No. 2 Effluent		
9/18/70	--	--	--	56 (0.45)	--
9/19/70	--	--	--	--	--
9/20/70	698 (0.96) (a)	104 (1.50)	135 (1.11)	28 (0.71)	--
9/21/70	--	--	--	--	--
9/22/70	--	--	--	69 (0.74)	--
9/23/70	460 (0.98)	133 (0 87)	153 (0.86)	48 (0.79)	--
9/24/70	--	--	--	56 (0.79)	--
9/25/70	--	--	--	--	--
9/26/70	726 (0.87)	135 (1.07)	115 (0.99)	52 (0.65)	--
9/27/70	--	--	--	34 (0.74)	--
9/28/70	626 (0.84)	178 (0.94)	206 (0.95)	58 (0.79)	--
9/29/70	--	--	--	72 (1.19)	--
9/30/70	--	--	--	106 (0.60)	--
10/1/70	--	--	--	74 (0.93)	--
10/2/70	598 (0.97)	158 (0.77)	202 (0.97)	68 (0.93)	--
10/3/70	--	--	--	52 (0.44)	--
10/4/70	--	--	--	44 (0.59)	--
10/5/70	375 (1.17)	140 (1.31)	144 (0.96)	35 (0.51)	--
10/6/70	--	--	--	34 (0.47)	--
10/7/70	--	--	--	52 (0.81)	65
10/8/70	--	--	--	58 (0.98)	--
10/9/70	--	--	--	54 (0.67)	--
10/10/70	--	--	--	32 (0.88)	--
10/11/70	518 (0.97)	144 (0.97)	158 (1.01)	42 (0.71)	--
10/12/70	--	--	--	44 (0.61)	--
10/13/70	--	--	--	27 (0.96)	--
10/14/70	--	--	--	29 (0.79)	--

(continued)

TABLE 26 (continued)

Date	Anaerobic Lagoon Influent	Anaerobic Lagoon No. 1 Effluent	Anaerobic Lagoon No. 2 Effluent	Aerated Stabilization Effluent	Facultative Lagoon Effluent
3/19/71	--	--	--	(0.60) 126/46 (0.33) (b)	133
3/20/71	--	--	--	(0.48) 126/54 (0.48)	--
3/21/71	--	--	--	(0.43) 188/62 (0.29)	58 (0.62)
3/22/71	1050 (0.40)	330 (0.55)	344 (0.51)	(0.48) 150/56 (0.38)	--
3/23/71	--	--	--	(0.43) 126/61 (0.26)	--
3/24/71	--	--	--	--	(0.40) 89/57 (0.35)
3/25/71	1045 (0.35)	420 (0.59)	551 (0.34)	--	--
5/20/71	--	--	--	(0.41) 214/72 (0.60)	(0.38) 134/54 (0.70)
5/21/71	1120 (0.72)	674 (0.55)	558 (0.62)	(0.39)222/68 (0.54)	--
5/22/71	--	--	--	(0.43) 164/88 (0.45)	--
5/23/71	--	--	--	(0.37) 138/41 (0.61)	(0.26) 144/50 (0.52)
5/24/71	830 (0.67)	569 (0.65)	488 (0.63)	(0.31) 153/29 (0.79)	--
5/25/71	--	--	--	(0.40) 158/32 (0.59)	--
5/26/71	--	--	--	(0.54) 138/34 (0.76)	(0.42) 124/44 (0.50
5/27/71	1060 (0.72)	620 (0.64)	558 (0.60)	(0.47) 174/41 (0.73)	

(a) Number in parenthesis is ratio of BOD_5/BOD_{20}.

(b) Total BOD/filtered BOD.

TABLE 27

COMPARISON OF LONG AND SHORT TERM BOD REMOVALS

Date	Anaerobic Lagoon Removal, %						Aerated Stabilization Removal, %			Overall Removal, %			BOD_5/BOD_{20}					Waste Feed
	BOD_5		BOD_{20}		COD													
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	BOD_5	BOD_{20}	COD	BOD_5	BOD_{20}	COD	Feed	No. 1 Anaerobic Lagoon	No. 2 Anaerobic Lagoon	Aerated Stabilization Effluent	Facultative Effluent	
9/18 to 10/15/70*	76	67	75	72	53	53	70	64	50	—	--	--	0.97	1.06	0.98	0.75	—	Dilute waste
3/19 to 3/25/71*	48	55	64	57	36	41	70	62	41	91	91	75	0.38	0.57	0.42	0.48	0.47	Previously treated anaerobically
5/20 to 5/27/71*	44	49	38	47	42	48	84	73	54	94	87	81	0.70	0.61	0.62	0.42	0.33	Additional conc. feed

* Note - Removal data for BOD_5 and COD are based on long-term averages containing these dates.

compounds were removed equally a slightly decreased ratio might be expected due to somewhat less degradable biological intermediates. An anaerobic process with inefficient methane fermentation could conceivably provide an increased ratio with the conversion of complex, slowly degradable organics to readily degradable volatile acids.

Examination of the BOD_5/BOD_{20} ratios with removals and waste feed data yields an interesting comparison of the anaerobic and aerobic processes. During the first period in which only a dilute waste was fed to the system the BOD_5/BOD_{20} ratio increases slightly through the anaerobic step. A marked decrease in the ratio (1.06 to 0.75) was observed in the aerobic step. The ratio greater than one reflects some difficulties in the long-term BOD determination which subsequently were overcome as discussed in Appendix II. Note that during this period BOD_5 and BOD_{20} removals were roughly equivalent and considerable greater than COD removals.

During the second experimental period the effluent from a long-retention anaerobic lagoon was added to the feed. Again an increase in the BOD_5/BOD_{20} ratio is observed through the anaerobic process with a decrease in the aerobic step (0.57 to 0.48 - the aerobic unit received the effluent from the No. 1 lagoon). The feed ratio was much lower in this case reflecting the presence of the well degraded waste in the feed. In this case BOD_{20} removals were greater or equal to BOD_5 removals in the anaerobic process. Less BOD_{20} than BOD_5 removal occurred in the aerobic process.

In the last experimental period dilute waste was supplemented with a concentrated waste. During this period the anaerobic system ratio declined less than did the aerobic system indicating less of a change in degradability with significant removal of organics. During the last period, anaerobic system BOD_5, BOD_{20} and COD removals all are roughly equivalent while aerobic BOD_5 removal is greater than BOD_{20} removal reflecting the lower degradation of more slowly reacting materials.

The long-term BOD data suggest that while the higher rate aerobic system may act to remove readily degradable materials preferentially, the anaerobic system acts on all degradable influent material with only a small change in waste degradability with organic removal. The similar BOD_5 and BOD_{20} removals observed in the anaerobic system compared to the greater BOD_5 than BOD_{20} removal in the following aerobic treatment support the hypothesis. Additional experimental work would be necessary for a definite confirmation of this suggested basic difference in the two process types.

SECTION IX

LAGOON PROCESS ECONOMICS

Design criteria developed from the demonstration study and supplemented by additional plant and small-scale pilot data for anaerobic lagoons have been used to make an economic evaluation of the anaerobic-aerobic system.

Investment and operating cost estimates have been prepared for three plant sizes. An investigation of the variation of construction cost with waste strength also was made for one plant size. Finally, a comparative cost estimate of the anaerobic-aerobic system and a completely mixed activated sludge system was made.

The Anaerobic-Aerobic System

The anaerobic-aerobic system for which cost studies were made includes pH adjustment, primary clarification, anaerobic lagoons, aerated stabilization, and facultative (solids removal) ponds.

The design basis for these studies and expected performance of each unit operation during summer and winter conditions is shown in Figure 24. The design detention time for each step at an influent BOD_5 level of 800 mg/l is listed. For the particular wastes tested a COD concentration of approximately 1600 mg/l would be expected. For some other petrochemical waste the degradable fraction of organics present could be expected to vary significantly from this observed 2:1 ratio. The major difference between warm and cold weather performance is due to the reduced performance of the anaerobic lagoon as temperature decreases. Overall BOD_5 removals of 95 and 90 percent are expected in summer and winter, respectively, at design conditions. Since the BOD:COD ratio could be expected to vary with different petrochemical wastes, the COD removal efficiency is not a particularly reproducible parameter between wastes. However, a removal of approximately 1.7 lb COD/lb BOD_5 removed was noted in the pilot studies. This parameter should be reasonably consistent between wastes.

A solids level of 200 mg/l is expected in the aerated stabilization system. Settling provided in the facultative ponds will produce an effluent with 75 mg/l of suspended solids. Some degradation of settled solids is expected. No long-term solids degradation data are available, but short-term data show that approximately fifty percent of the suspended solids will be degraded in one year. Cost estimates are based on periodic dewatering and incineration of waste sludges.

A summary of the major assumptions used in preparation of the cost estimates is provided in Table 28. Table 29 contains a tabulation of the major structural and mechanical features for the 0.5, 10.0, and 25.0 million gallon per day plants chosen for study.

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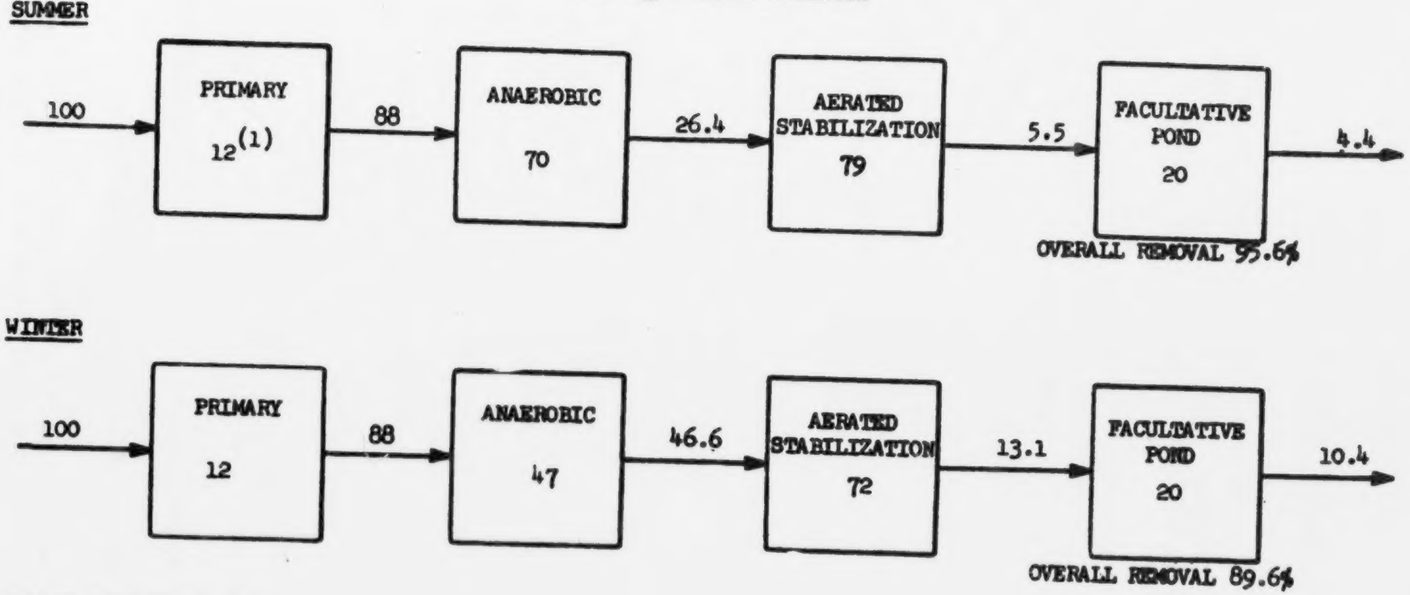
FIGURE 24

TYPICAL REMOVAL EFFICIENCIES FOR ANAEROBIC-AEROBIC SYSTEMS

BASIS - 100 LB. BOD_5 TO PRIMARY CLARIFIER

800 mg/1 WASTE STRENGTH


SUMMER
100
PRIMARY
12(1)
88
ANAEROBIC
70
26.4
AERATED STABILIZATION
79
5.5
FACULTATIVE POND
20
4.4
OVERALL REMOVAL 95.6%
WINTER
100
PRIMARY
12
88
ANAEROBIC
47
46.6
AERATED STABILIZATION
72
13.1
FACULTATIVE POND
20
10.4
OVERALL REMOVAL 89.6%

DESIGN DETENTION TIMES

ANAEROBIC - 15 DAYS
AERATED STABILIZATION - 3 DAYS
FACULTATIVE PONDS - 8 DAYS

NOTES

(1) Values in unit box represent percent BOD_5 removal across that operation or process in the pilot operations

(2) A removal of 1.7 lb COD/lb BOD_5 removed was noted in pilot studies

TABLE 28

MAJOR ASSUMPTIONS OF THE STUDY

1. Earthwork slopes are two horizontal units for each vertical unit.

2. Piling is required under all major structures.

3. A Gulf Coast location is assumed.

4. All earthen basins are lined with four inches of concrete from the top of the slope to two feet below the water surface unless otherwise noted.

5. Basin interconnect piping is low-head corrugated metal drainage pipe with protective coating.

6. All costs adjusted to 1971 dollars.

TABLE 29

ANAEROBIC-AERATED STABILIZATION SYSTEM

SUMMARY OF MAJOR EQUIPMENT

	Plant Size (mgd)		
	0.5	10.0	25.0
Neutralization			
No. of Compartments	2	2	4
Materials of Construction	Concrete	Concrete	Concrete
Dimensions, ft			
Plan	6.0 x 7.5	20 x 20	22 x 22
Depth	8	12	12
Horsepower	10	60	80
Piling	Yes	Yes	Yes
Control Loops	2	2	4
Primary Clarification			
No. of Units	2	2	4
Dimensions, ft			
Diameter	18	80	90
SWD	9	9	9
Freeboard	3	3	3
Piling	Yes	Yes	Yes
Anaerobic Ponds			
No. of Units	2	2	4
Dimensions, ft			
Length (1)	180	1060	1155
Width	255	676	780
Depth	15	15	15
Aerobic Basin			
No. of Units	2	2	4
Dimensions, ft			
Length (1)	187	676	770
Width	72	325	350
Depth	10	10	10
Aerators (mechanical, floating)			
Number	6	28	50
Horsepower	25	75	100

(continued)

TABLE 29 (continued)

	Plant Size (mgd)		
	0.5	10.0	25.0
Facultative Ponds			
No. of Units	4	4	4
Dimensions, ft			
Length (1)	162	677	762
Width	162	677	1475
Depth	6	6	6

(1) Length and width dimensions are measured at water surface.

The Activated Sludge System

Design parameters for the activated sludge system used in this study were developed from pilot scale work conducted on wastewater similar to that used for the anaerobic-aerobic study (3). The treatment system consists of pH adjustment, primary clarification, equalization, activated sludge and final clarification. Sludge disposal costs were estimated by adjusting published unit cost data for investment and operating costs to incorporate bench-scale dewatering data.

The principal design criteria for the biological reactor and final clarification tanks are tabulated below:

Detention Time	17 hours
Food to Biomass Ratio	0.45/day
MLSS	2500 mg/l
BOD_5 Removal	88%
Clarifier Overflow Rate	600 gal/day-ft^2

Cost estimates for the activated sludge system include two features which are not included in the anaerobic-aerobic system. A concrete lining is included in the aeration basins for erosion protection. Fixed mounted surface entrainment aerators are included to facilitate maintenance of closely spaced equipment. No estimate of COD removal efficiency was made for the activated sludge system.

Cost Estimates

Anaerobic-Aerated Stabilization

Construction cost estimates were prepared for plants with daily flow of 0.5, 10.0, and 25.0 million gallons. A waste strength of 800 mg/l BOD_5 was selected for the base case estimate. This study yielded a cost of \$168, \$33, \$28 per pound of BOD per day applied with increasing plant size. A construction cost summary is presented in Table 30. The respective operating cost for each plant is shown in Table 31. Operating costs for the plants are \$0.073, \$0.022, \$0.018 per pound BOD applied as size increased.

A further extension of the study was made by holding the waste flow constant to a 10.0 MM gallon per day plant and increasing waste strength to 2000 mg/l. The only significant increase in construction cost with increasing waste strength is for aeration capacity. Figure 25 presents the variation in total and unit construction cost. Operating cost increase with waste strength is related to increases in reagent dosage and aeration horsepower. A significant decrease in cost per pound of BOD_5 applied can be observed in Figure 26.

TABLE 30

CONSTRUCTION COST SUMMARY

ANAEROBIC-AERATED STABILIZATION SYSTEM

System Component	Plant Size (mgd) 0.5	10.0	25.0
Neutralization			
Structural	$ 6,800	$22,000	$51,000
Mixing	3,000	9,300	15,500
Reagent Storage	30,400	30,400	60,800
pH Control	12,000	12,000	24,000
Clarification			
Structural	20,700	123,600	279,300
Mechanical Equipment	20,700	59,000	146,000
Anaerobic Ponds			
Earthwork	70,800	326,500	516,500
Concrete Liner	1,900	39,300	104,300
Aerobic Basin			
Earthwork	63,800	209,500	368,300
Concrete Liner	10,000	32,800	77,100
Aeration Equipment	45,000	448,000	900,000
Electrical Support	22,800	85,500	194,000
Facultative Ponds			
Earthwork	36,500	135,500	323,000
Concrete Liner	15,400	59,100	239,000
Piping	38,700	167,400	412,600
Instrumentation	30,000	56,000	115,000
Building and Lab Equipment	34,000	51,000	70,000
Site Preparation	22,000	49,100	93,600
Land at $1,000/acre	9,000	100,000	230,000
Sub-Total	$506,000	$2,016,000	$4,220,000
Construction Contingency	51,500	209,000	430,000
Construction Cost	$560,000	$2,225,000	$4,650,000
Cost/Lb. BOD Applied	$ 168	$ 33	$ 28
Cost/1000 Gal.	$ 1,120	$ 222	$ 186

TABLE 31

ESTIMATED OPERATING COST

ANAEROBIC-AERATED STABILIZATION SYSTEM

	Plant Size, MM gal/day		
	0.5	10.0	25.0
Operating Labor & Supervision			
Technical Supervision	$ 5,800	$17,500	$17,500
Day-Shift Supervisor	6,200	12,500	12,500
Operators	36,400	72,800	72,800
Laboratory Analysis	5,200	18,000	20,000
Mechanic-Instrument Man	5,200	10,400	15,600
Reagents			
NH_3 - 1 Lb N/20 Lb. BOD	500	10,000	25,000
H_3PO_4 - 1 Lb P/100 Lb. BOD	200	23,800	59,500
H_2SO_4 - 3000 Lb - 93% Acid/MM Gal	7,800	150,000	375,000
Power (1)			
Aeration Horsepower x 1.15	11,400	157,000	372,000
Maintenance			
2.0 Percent of Construction Cost	10,000	44,000	80,000
Operating Supplies	300	2,000	4,100
Annual Operating Cost	$ 90,000	$518,000	$1,054,000
Sludge Disposal (2)	20,000	25,000	70,000
Amortize Investment - 20 yrs at 6%	49,000	194,000	405,000
Total Annual Cost	$159,000	$737,000	$1,529,000
Cost/1000 Gallons	$0.87	$0.21	$0.17
Cost/Lb BOD Removed	$0.14	$0.034	$0.028
Cost/Lb COD Removed	$0.081	$0.020	$0.016

(1) Power at $0.01 per kw-hr

(2) Annual operating plus investment costs

FIGURE 25
VARIATIONS IN COST WITH WASTE STRENGTH

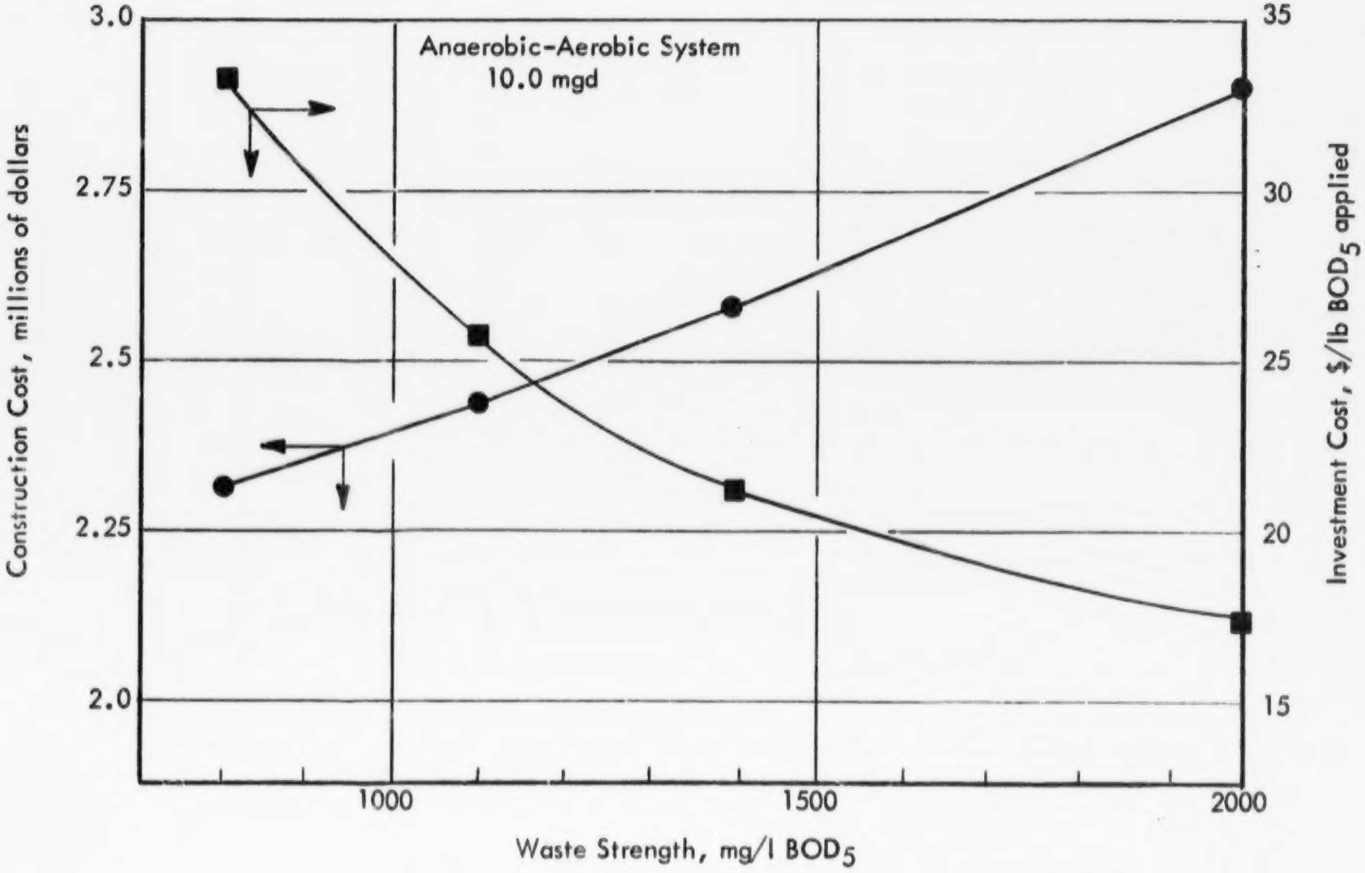
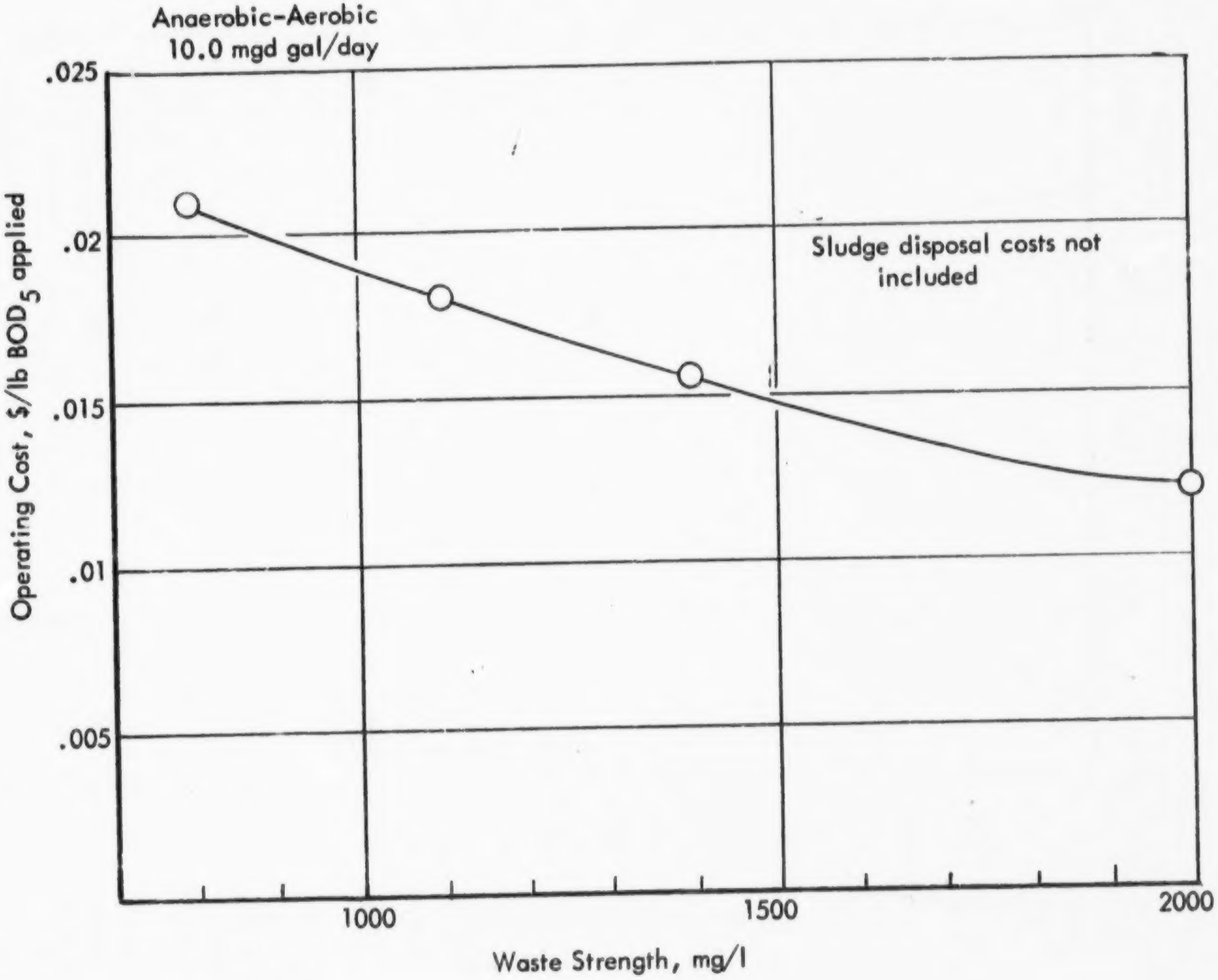


FIGURE 26

VARIATION IN OPERATING COST WITH WASTE STRENGTH



Activated Sludge

Investment and operating cost data for a 10.0 million gallon per day plant are presented in Tables 32 and 33. A total cost of \$0.043 per pound of BOD removed is forecast based on amortizing the capital investment at six percent interest over a 20 year period.

System Comparison

The anaerobic-aerated stabilization system would be considered as a substitute for a completely-mixed activated sludge system. A comparison of the two systems is presented below:

SYSTEM COMPARISON

10.0 mgd

800 mg/l

	Anaerobic/ Aerated Stabilization	Activated Sludge
Land Required (acres)	100	10
Effluent BOD_5 (mg/l)		
Warm	35	84
Cold	85	84
Effluent Suspended Solids (mg/l)	75	100
Cost/lb BOD_5 Removal	\$0.034	\$0.043

The anaerobic-aerated stabilization system will produce an effluent at least as good as the activated sludge plant. A significant reduction in unit removal cost can be expected. High land requirements and reduced efficiency at low temperature are negative factors to be weighed.

Cost comparisons are based on total annual cost for each system. Construction cost estimates for each system are based on actual layout and quantity estimates for all components except sludge disposal. This construction cost estimate was reduced to an annual cost to amortize the investment. The second element of annual cost was estimated operating cost. The final element of total cost is a unit cost for sludge disposal derived from the literature. This cost reflects both investment and operating allocations. The development of the unit cost figures is shown in Table 33.

TABLE 32

CONSTRUCTION COST SUMMARY

ACTIVATED SLUDGE SYSTEM

10.0 MM gal/day
800 mg/l

	Construction Cost
Neutralization	
Structural	$ 22,000
Mixing	9,300
Reagent Storage	30,400
pH Control	12,000
Primary Clarification	
Structural	123,600
Mechanical Equipment	59,000
Equalization	
Structural	78,100
Concrete Liner	17,400
Mixing	20,000
Aerobic Basin	
Earthwork and Roadway	25,300
Concrete Liner	90,000
Aeration Equipment	504,000
Aeration Equipment Support	280,000
Electrical Support	67,000
Final Clarification	
Structural	214,900
Mechanical Equipment	112,000
Piping	113,700
Instrumentation	50,000
Building & Lab Equipment	56,000
Site Preparation	28,300
Land at $1,000/acre	10,000
Sub-Total	1,923,000
Construction Contingency	192,000
Construction Cost	$2,115,000

TABLE 33

COST COMPARISON

10.0 MM GAL/DAY SYSTEMS

800 mg/l

	Activated Sludge	Anaerobic-Aerated Stabilization
Operating Labor and Supervision		
Technical Supervision	$ 17,500	$ 17,500
Day-Shift Supervisor	12,500	12,500
Operators	72,800	72,800
Laboratory Analysis	18,000	18,000
Mechanic-Instrument	10,400	10,400
Reagents		
NH_3 - 1 Lb. N/20 Lb. BOD	13,300	10,000
H_3PO_4 - 1 Lb. P/100 Lb. BOD	49,000	23,800
H_2SO_4 at 3000 Lb of 93% Acid/MM Gal	150,000	150,000
Power		
Aeration Horsepower x 1.15	210,000	157,000
Maintenance		
2.0% of Construction Cost	42,000	44,000
Operating Supplies	2,000	2,000
Annual Operating Cost	598,000	518,000
Sludge Disposal (1)	153,000	25,000
Amortize Investment - 20 yrs. at 6%	184,500	194,000
Total Annual Cost	935,000	737,000
Cost/Lb. BOD_R	$0.043	$0.034

(1) Sludge data unit costs include investment and operating cost and are based on A Study of Sludge Handling and Disposal by R. S. Burd, Publication No. WP-20-4, Federal Water Pollution Control Administration, May 1968.

SECTION X

ALTERNATIVES STUDIED

The alternative processes of anaerobic contact digestion and anaerobic trickling filters were studied on a bench scale with synthetic wastes at the Union Carbide Technical Center, South Charleston, West Virginia and on a semi-pilot scale at Union Carbide's Texas City, Texas Plant using actual wastes.

Description of Wastes Treated

The synthetic waste treated in the bench-scale units is described in Table 34. The units were started from domestic digesting sludge on a readily degradable mixture of diluted acetic acid, ethanol and ethylene glycol. After active cultures were developed the simulated chemical waste which contained eleven chemicals at equal theoretical oxygen demand was used. Trace elements were added as were ammonia and phosphate compounds for nutrient values in both feeds. Two strengths of simulated waste were used, one of about 20,000 mg COD/l (25,000 mg theoretical oxygen demand/l) and another of 2,000 mg COD/l (2500 mg TOD/l). The dilute waste was prepared by adding one part of the concentrated waste to nine parts tap water.

Petrochemical wastes were treated in semi-pilot scale studies at two concentration levels. The actual petrochemical effluent streams from the Texas City Plant consisted of one stream having an average COD of about 1500 mg/l, the other about 15,000 mg/l. The streams were blended with tap water to provide an in-between composition feed for the filters. Sulfates in the feed ranged in concentration from less than 200 to more than 1500 mg/l. Specific organic chemicals detected in the feed are listed in Table 35.

Contact Digestion

Bench-scale contact digestion experimentation was performed in four completely mixed 5-gallon carboys illustrated schematically in Figure 2. Tube and packed bed type clarifiers were used for solids separation in the continuously fed systems. Pilot scale studies were performed in a 5600-gallon, heated, hydraulically mixed reactor equipped with an internal, tube type clarifier (Figure 27).

The bench-scale units were operated to determine feasible conditions for experimentation in the pilot scale facility and to evaluate two types of solids separation (tube clarifier and packed bed) and the effect of colloidal asbestos on solids separation and digester performance.

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TABLE 34

ANAEROBIC TREATMENT OF SYNTHETIC ORGANIC WASTES

MIXED CHEMICALS - DIGESTER FEED

Date First Used	4-29-69
Theoretical Oxygen Demand, mg/l	25,000
Measured COD, mg/l (1)	20,000
Measured BOD_5 (1)	19,600
Substrate	
Acetic Acid	2124
Benzoic Acid	1165
Propionic Acid	1505
Acetaldehyde	1248
Phenol	955
Butanol	878
Ethanol	1093
Vinyl Acetate	1361
Butyl Acetate	1033
Monoethanolamine	914
Diethylene Glycol	1505
Buffer-Nutrient	
$(NH_4)_2CO_3 \cdot H_2O$	4292
$NaH_2PO_4 \cdot H_2O$	542
KH_2PO_4	542
Trace Elements	
$FeCl_3$	180
$MnSO_4 \cdot H_2O$	3.08
$CoCl_2 \cdot 6H_2O$	4.04
MoO_3	1.53
$ZnSO_4 \cdot H_2O$	5.32

Note: Concentrated mixtures were diluted with tap water as required.

(1) Mean of several analyses of diluted feeds recalculated to original strength.

(2) Provided ratio COD/N/P $\cong$ 100/5/1

TABLE 35

DETECTED CONSTITUENTS OF WASTE USED AS FEED IN SEMI-PILOT SCALE STUDIES

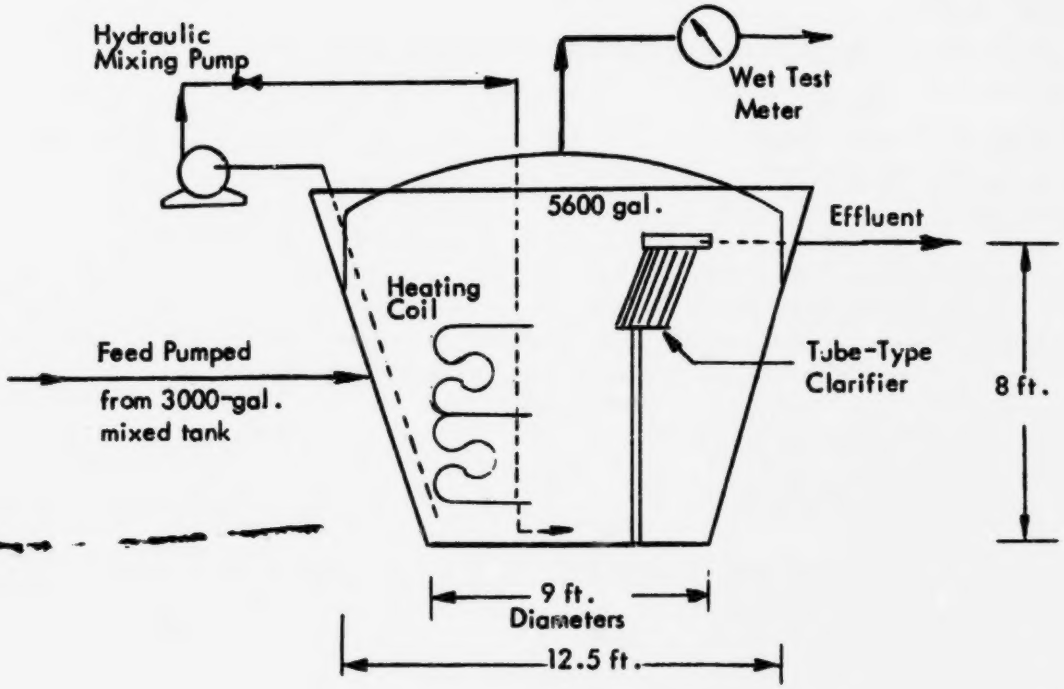
Acetaldehyde
Acetic acid
Acetone
Ethylenediamine polymers
Benzene
Isobutanol
n-Butanol
Bis(2-chloroethyl) ether
Ethanol
Ethylene dichloride
Ethylene glycol
Isobutyraldehyde
n-Butyraldehyde
Hexanol
Methanol
Isopentanol
n-Pentanol
Isopropanol
n-Propanol
Propionaldehyde
Methyl ethyl ketone

Waste tested at two dilutions: 1,500 and 15,000 mg COD/liter

NH_4OH and H_3PO_4 added as nutrients; H_2SO_4 and NaOH added to adjust pH

FIGURE 27

SEMI-PILOT CONTACT DIGESTER


Hydraulic Mixing Pump
Wet Test Meter
5600 gal.
Effluent
Heating Coil
Feed Pumped
from 3000-gal. mixed tank
Tube-Type Clarifier
8 ft.
9 ft. Diameters
12.5 ft.

The tube type of gravity clarifier separation system, illustrated in Figures 2 and 27, exploits the theoretical advantages of low hydraulic flow per unit surface area of clarifier (17). The tubes are inclined so as to be self-cleaning; the solids fall back into the reactor or into a storage facility for recycle. In the laboratory packed bed system, also alluded to in Figure 2, the solids are filtered from the effluent and retained in the bed of gravel or glass beads. Periodic backflushing returns the solids to the reactor.

The bench scale units operating on the dilute synthetic waste feed, described in Table 34, gave satisfactory results of up to 80% chemical oxygen demand (COD) reduction at hydraulic retention times (HRT) exceeding approximately 5 days (Figure 28), while units treating the concentrated wastes experienced between 10 and 50% COD removal efficiency at 7 to 10 day HRT. At detention times of less than 4 days the performance in some units treating dilute waste deteriorated indicating either insufficient reaction time or organism washout.

The solids retention time (SRT) in the short HRT experiments decreased somewhat due to less efficient solids capture at the increased flow and was in some cases relatively near the minimum generation time of methane bacteria. Also, although the SRT decreased both in the units receiving colloidal asbestos and those not receiving asbestos, the organic removal efficiency remained approximately steady in those units receiving asbestos. It is hypothesized that the asbestos provides growth sites for the methane bacteria and may serve to selectively concentrate these or other surface cultures as well as aid in overall organism separation. The range of SRT covered was 5 to 130 days while loadings were 10 to 190 lb. COD/1,000 cu ft/day.

The effects of asbestos addition in dilute waste treatment are further shown in Figure 29. The organic loading was increased by feeding a more concentrated waste while holding the HRT above 5 days. The resulting removal per unit volume increases but at a lesser rate. A line with an intercept of zero and a slope of one would indicate constant removal efficiency. The steeper slope with the units receiving asbestos indicates increased efficiency, at least at loading of 15 lb. COD/1,000 cu.ft./day or greater. The asbestos served to increase the digester suspended solids level and to avert solids separation difficulties.

The purpose of the bench scale experimentation was to determine feasible operational conditions and preliminary design information. As a result, the units were not necessarily allowed to come to steady state, but conditions were changed after an adequate removal was established. The bench scale units did point out the effectiveness of the less costly tube type of clarifier and the advantages of colloidal asbestos in the feed.

FIGURE 28

EFFECT OF RETENTION TIME ON COD REMOVAL IN LABORATORY CONTACT DIGESTERS

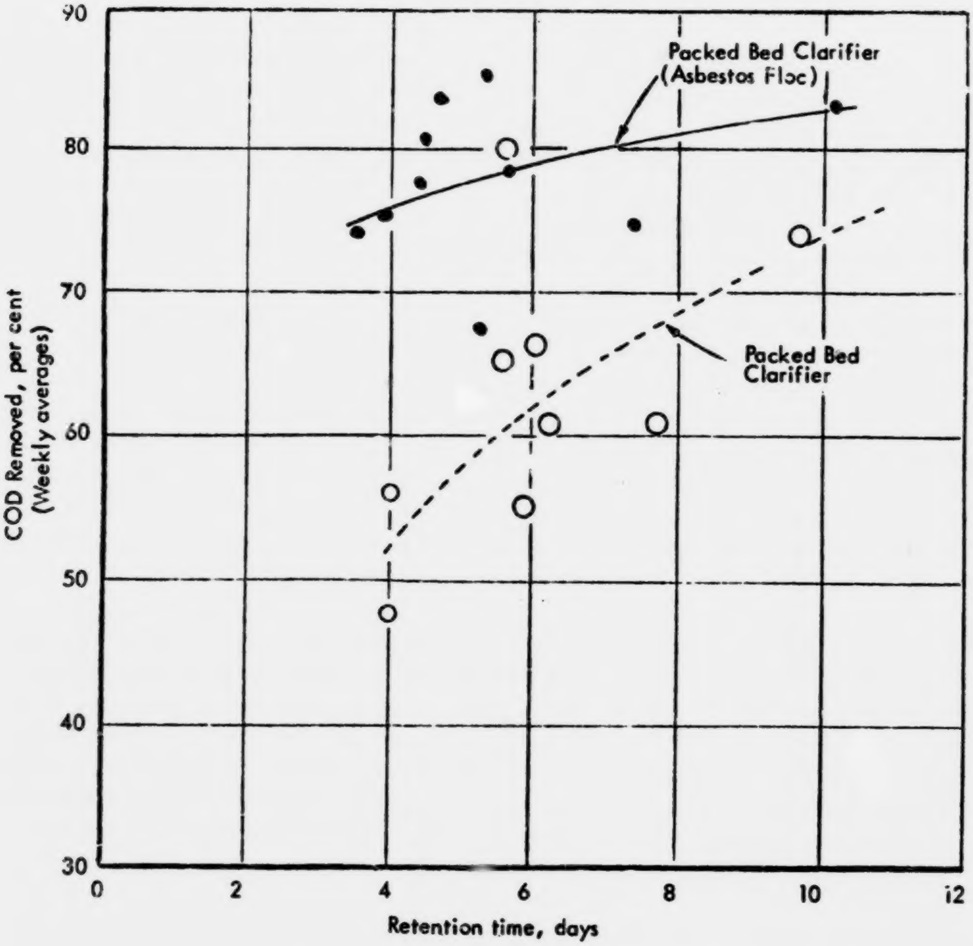
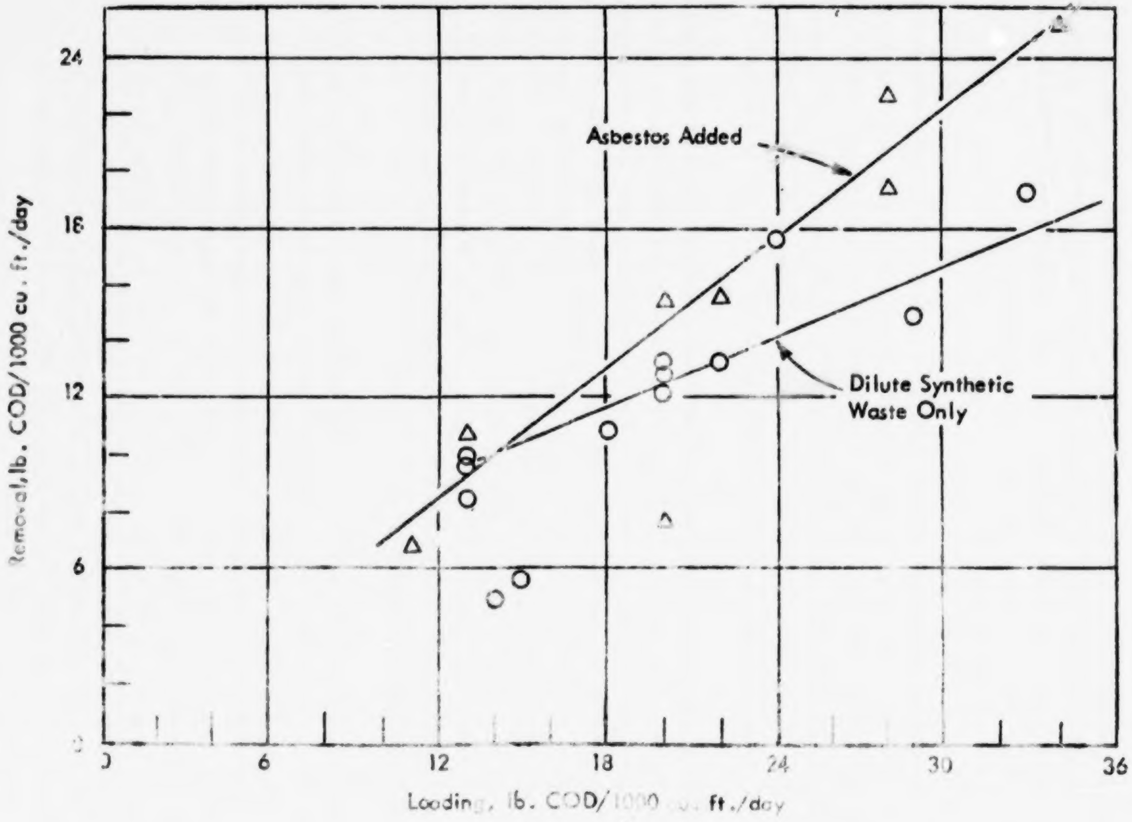


FIGURE 29

REMOVAL VS LOADING FOR CONTACT DIGESTER
BENCH SCALE UNITS



Pilot scale experiments were performed on concentrated wastewater only, as full scale contact reactor facilities were visualized as economically unfeasible for a large volume, dilute waste stream. Colloidal asbestos was added to the pilot unit feed at a 25 mg/liter level to aid in solids separation.

The COD removals experienced for 6 and 10 day HRT were 21 and 34%, respectively, as illustrated in Figure 30. These removals were not as substantial as desired but were consistent with those experienced in the bench scale units treating concentrated wastes at similar loadings. Figure 31 illustrates the relationship observed between volumetric loading and removal efficiency for both bench and pilot scale units. Suspended solids were maintained at a suitable level of 5,000 mg/liter in the pilot digester through 85 to 95% solids capture efficiency in the tube clarifier.

One factor possibly limiting semi-pilot-scale performance was the high influent sulfate level. The 500-to-800 mg/l level of sulfates was reduced to sulfides, with 50 to 100 mg/l sulfides remaining in the mixed liquor and the remainder lost as hydrogen sulfide in the digester gas. The oxygen demand of contained sulfides was included in the effluent COD measurements in all experimental results. The sulfide levels found were marginal for inhibition of methane bacteria. Sulfides can be tolerated at 50 to 100 mg/l, can be acclimated to up to 200 mg/l, and are definitely toxic at above 200 mg/l (18). Means of combating sulfide toxicity would be precipitating with heavy metals or mixing the unit by gas recycle to allow scrubbing of additional sulfide from the liquid.

The high volatile acid level also could be a cause of semi-pilot-scale digester performance limitation. Feed volatile acids ranged from 3000 to 4000 mg/l as acetic and increased with residence in the reactor. Although Andrews (19) has indicated that dissociated volatile acids are inhibitory at approximately 2000 mg/l, others (20) have indicated inhibition to be dependent on the associated cation. Batch studies of the digester mixed liquor yielded good methane production showing a methanogenic culture was present, but possibly inhibited in treating the actual concentrated waste stream. In contrast, volatile acids in the dilute waste feed in bench scale units which provided acceptable COD removal were approximately 400 mg/l as acetic acid and dropped to less than 200 mg/l in the reactor indicating good conversion of the produced acids.

Anaerobic Filters

The performance of anaerobic filters was evaluated both in 1.4 gal bench units and in 35 gal pilot scale units (Figure 32). Laboratory units were packed with 1-in berl saddles yielding a 58% void volume, while 1-in diameter river gravel was used in pilot studies (41% void volume). The laboratory unit was 3.5 in in diameter and 25 in high, while these dimensions were approximately tripled in the pilot unit. Annular ring baffles were installed to prevent short-circuiting along the sides.

FIGURE 30

SEMI-PILOT SCALE CONTACT DIGESTER PERFORMANCE

INFLUENT AND EFFLUENT COD

Period A - 10 Day Detention - Increasing Feed Strength
B - 10 Day Detention - Full Strength
C - 6 Day Detention - Full Strength

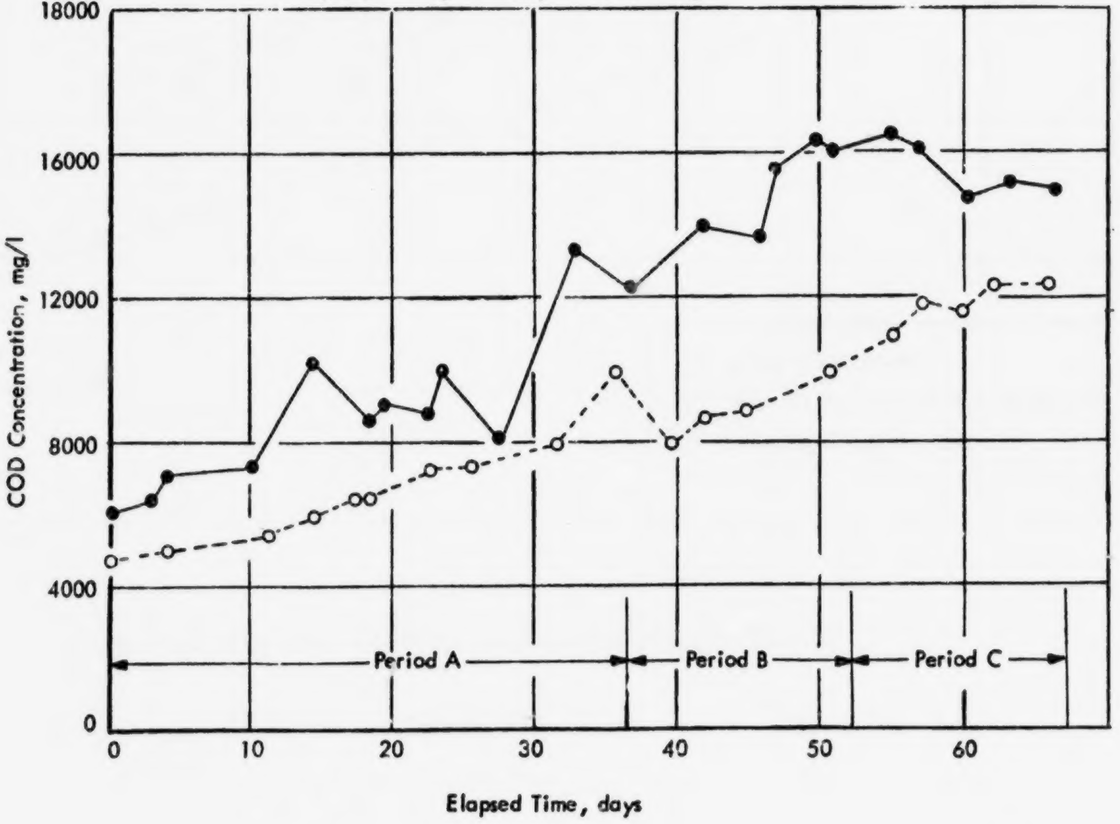
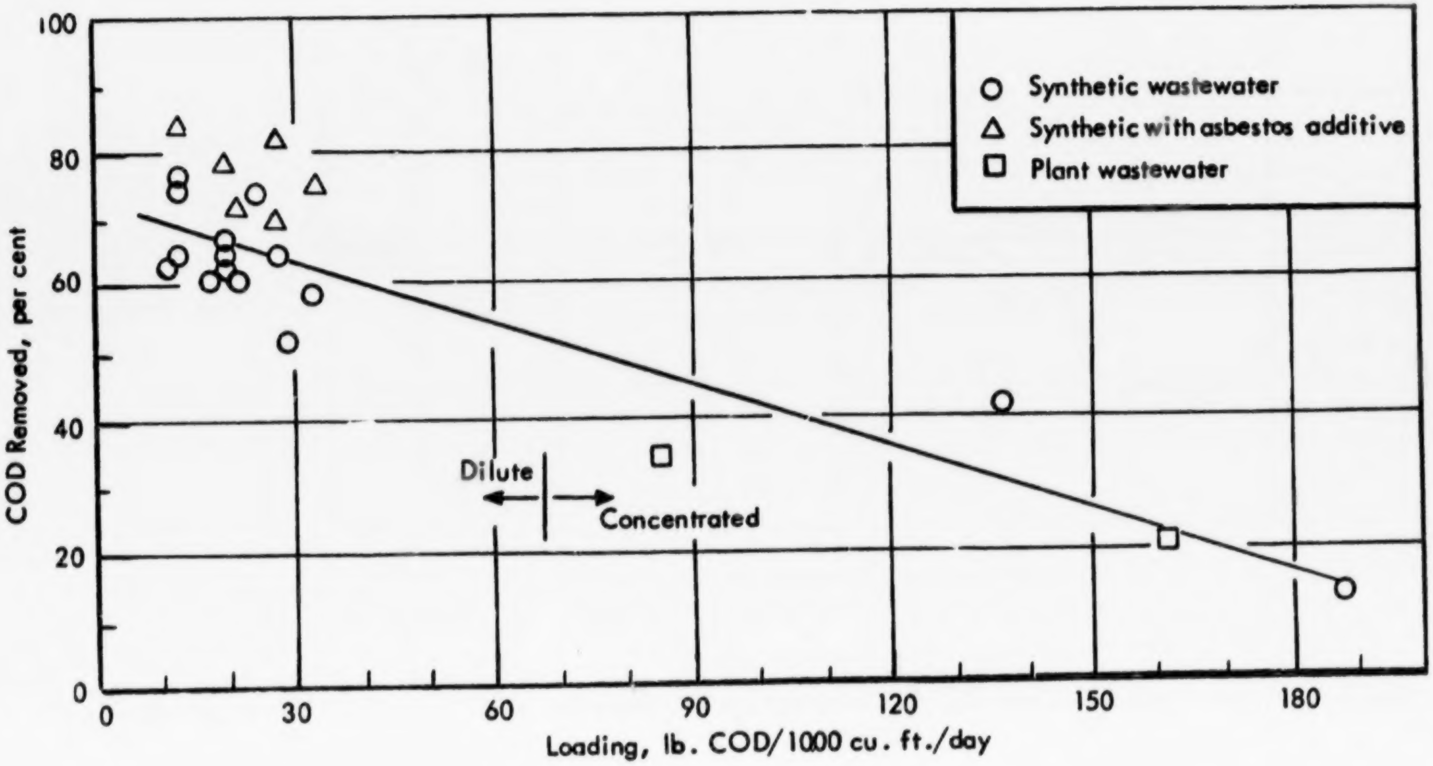


FIGURE 31

CONTACT DIGESTER, EFFICIENCY AT VARIOUS LOADINGS



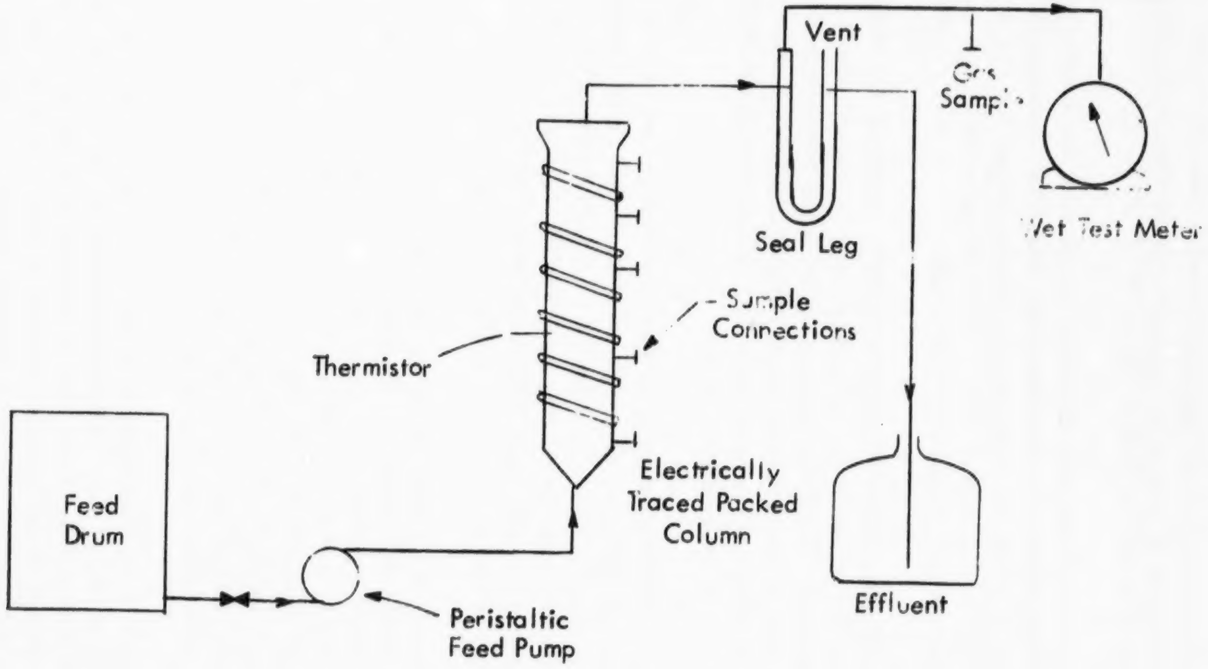

Vent
Gas Sample
Wet Test Meter
Seal Leg
Sample Connections
Thermistor
Electrically Traced Packed Column
Feed Drum
Peristaltic Feed Pump
Effluent

FIGURE 32
ANAEROBIC FILTERS

Both dilute and concentrated simulated wastes were treated in laboratory scale units, while a concentrated plant waste diluted with tap water was treated in the pilot studies. Both types of experimental units were heated to 32° to 35°C.

The anaerobic filters operated satisfactorily on dilute wastes over the loading range tested, up to 130 lb COD/1,000 cu ft/day based on total filter volume. For the type of substrate described in Table 34, removal efficiencies ranged from 60 to 80% over a retention time of 0.5 to 2.0 days at 32°C. The average weekly data were grouped around a 70% removal at 1.0 day HRT (Table 36).

The bench scale filter receiving concentrated wastes failed, probably due to the introduction of a concentrated synthetic petrochemical feed to this unit started on an alcohol and volatile acid feed. The waste loading per se to the concentrated unit should not have been enough to cause failure unless rapid production of volatile acids combined with the high level in the feed was inhibitory to the methanogenic culture or a specific constituent was at an inhibitory level.

The pilot scale filters were started by seeding with an acclimated anaerobic sludge which was actively producing methane. Three filters were started under identical conditions, thought to be conservative, to achieve a high initial removal level. However, satisfactory removals were never obtained over the 90 day run in spite of attempts to optimize operating conditions. COD reductions at 34°C and a retention time of 3 days tended to stabilize at 10 to 13% as shown in Figure 33.

Methane was produced during the course of pilot filter operation, indicating that some methanogenic population was present. The methane could also have been produced directly from simple substrates in the feed such as methanol and reduction of carbon dioxide by hydrogen without conversion of produced or fed volatile acids. Feed volatile acids ranged from 600 to 1,500 mg/liter as acetic. This level increased approximately 30% through the units, indicating an active acid forming population and an insufficient methane population to convert the produced acids. Volatile acid levels found in the unit were below levels reported to be inhibitory.

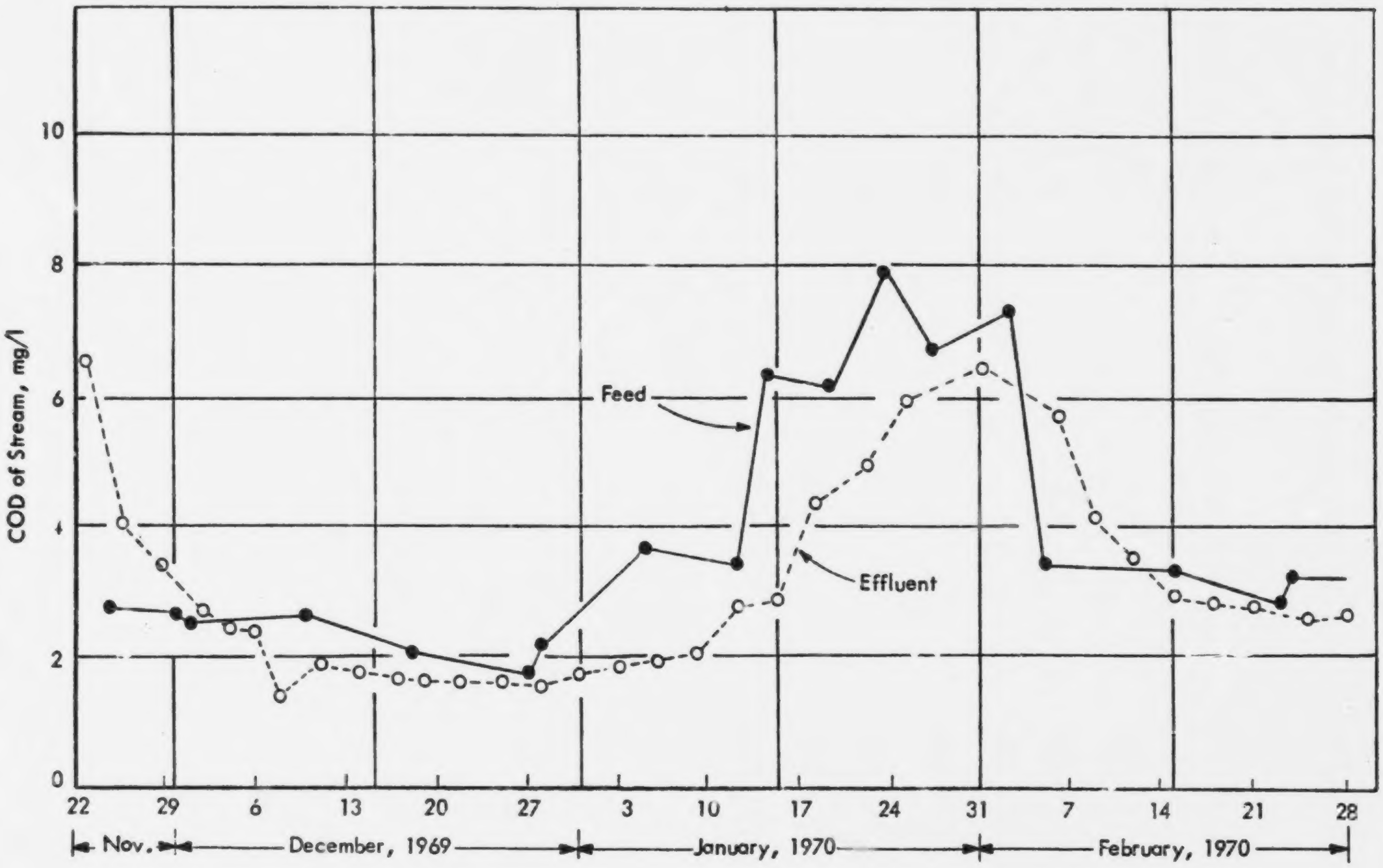
Sulfates at 150 to 200 mg/l in the feed were reduced to sulfides with some escaping as hydrogen sulfide in the produced gas. Effluent dissolved sulfides ranged from 50 to 100 mg/l. Sulfide toxicity again was only a marginal problem, but varying sulfate feed levels or a dropoff in sparging gas production would cause toxicity problems. Inhibition could have resulted from a specific chemical in the feed or one formed in an intermediate breakdown step.

TABLE 36

LABORATORY ANAEROBIC FILTER STUDIES ON DILUTE WASTE

Study Period, weeks	Average Retention Time, days	Average COD Removal, %	
1 - 8th	2.7	45	Start-up
9 - 12th	7.5	31	
13 - 15th	1.9	76	
16 - 18th	1.1	73	
19 - 21st	0.92	69	
22 - 24th	0.86	70	
25 - 27th	0.69	64	

FIGURE 33
PERFORMANCE OF SEMI-PILOT SUBMERGED FILTERS



Specific Organic Analyses

The overall performance of the pilot scale contact digestion and anaerobic filter units can be examined more closely if the specific organic compounds and removals for each process are compared. Tables 37 and 38 contain a listing of chromatographically identified compounds from the contact digester and filters while those for the lagoons were listed previously in Tables 12 and 13. The analyses were made on a number of composite or grab samples while the mean level for each compound is the average for the number of times observed.

In both the contact digestion and anaerobic filter process a decrease in the concentration of all applied organics except volatile acids was noted. An increase in the concentration of metabolic intermediates such as acetic, propionic, butyric, and C_5 acid compounds resulted in a very low net carbon removal. Both of the alternative processes were reasonably efficient in alteration of the non-volatile-acid organics even though little absolute oxygen demand removal was evidenced as shown in Table 39. In fact, the removal of chromatographically identifiable carbon compounds other than volatile acids is similar in all of the processes studied, varying from 58 to 73 percent with the lowest level existing in a lightly loaded lagoon system. The primary performance difference between the semi-pilot scale processes was thus the fact that the lagoons were able to maintain a culture capable of metabolizing the intermediate volatile acids metabolites to methane and hence have a suitable oxygen demand removal, while the contact digester and anaerobic filter were not able to maintain such a culture.

Two theories may be used to explain the discrepancy in the utilization of intermediates between the high-rate and lagoon systems. First, some component of the waste might be degradable in moderate concentrations but inhibitory at greater levels. Support of this hypothesis is indicated by the batch anaerobic degradation tests in which the well acclimated pilot lagoon bottom sludges were inhibited when fed 35 lb COD/1000 ft^3 of waste. Such a component could be degraded and diluted to below the inhibitory level without causing problems in the lagoon system. Second, a separate microbial culture may exist in the lagoon system capable of utilizing the intermediates. Such a culture has been shown to exist and to utilize acetate in the photosynthetic experiments. Certainly both theories constitute a part of the reason for the ability to degrade materials in a lagoon which could not be degraded in the high rate processes. Before either high rate process can be utilized in treatment of petrochemical wastes some alteration will be required to provide conditions so that methane fermentation will occur and a significant removal of oxygen demand will result. An exception would be if the treatment objectives were to convert complex, problem organics to simple, degradable substrates.

TABLE 37

REMOVAL OF SPECIFIC COMPOUNDS IN CONTACT DIGESTION STUDIES

Compound	Feed (a)				Effluent				Conversion, mg/l compound / mg/l total carbon
	Mean	Maxi-mum	Mini-mum	Number of Occurrences	Mean	Maxi-mum	Mini-mum	Number of Occurrences	
Acetaldehyde	44	50	30	10	9	10	5	5	1.83
Methanol	155	225	75	10	37	80	10	11	2.67
Ethanol	74	100	45	10	52	80	30	11	1.92
Acetone	100	550	30	10	25	50	10	11	1.61
Isopropanol	62	100	45	10	56	100	15	12	1.67
n-Propanol	269	350	50	4	43	45	40	2	1.67
Methyl ethyl ketone	50	50	50	1	0	0	0	0	1.50
Acetic acid	788	1900	180	10	973	1550	365	12	2.50
Isopentanol	331	640	150	7	80	100	40	5	1.47
Ethylene glycol	306	500	200	8	61	70	50	6	2.58
n-Butyraldehyde	91	115	50	6	28	50	15	5	1.50
Hexanol	139	260	50	7	50	50	50	1	1.42
Pentanol	88	100	75	2	0	0	0	0	1.47
Isobutyraldehyde	102	160	50	5	30	40	15	5	1.50
Propionic acid	0	0	0	0	525	1200	40	10	2.06
Isobutanol	241	300	50	7	94	120	10	9	1.54
Butyric acid	0	0	0	0	357	850	60	9	1.28
C_5 acid	0	0	0	0	200	200	200	1	1.70
n-Butanol	210	280	50	7	61	100	10	10	1.54
Propionaldehyde	50	50	50	1	0	0	0	0	1.61
Unknown	0	0	0	0	200	370	100	7	--
Benzene	50	50	50	1	0	0	0	0	1.08

(a) Concentrations are as mg/l total carbon

(b) Average of 12 samples, composite and grab

(c) Detention time 6 to 10 days
Temperature 34°C
Loading 60-160 lb COD/1000 cu ft/day

TABLE 38

REMOVAL OF SPECIFIC COMPOUNDS IN ANAEROBIC FILTER PILOT STUDIES (a)

Compound (c)	Feed (b)				No. 1 Filter Effluent				No. 2 Filter Effluent				No. 3 Filter Effluent			
	Mean	Maximum	Minimum	Number of Occurrences	Mean	Maximum	Minimum	Number of Occurrences	Mean	Maximum	Minimum	Number of Occurrences	Mean	Maximum	Minimum	Number of Occurrences
Acetaldehyde	39	75	10	9	9	10	5	4	7	10	5	3	12	20	5	3
Methanol	59	100	10	9	19	50	5	6	21	50	10	5	21	50	10	5
Ethanol	49	100	20	9	7	10	5	3	18	35	5	4	13	20	5	2
Acetone	38	50	10	9	29	25	5	7	28	60	10	6	33	70	10	6
Isopropanol	52	150	5	9	34	95	5	7	36	120	10	7	35	90	10	7
n-Propanol	35	40	30	2	5	5	5	1	0	0	0	0	0	0	0	0
Methyl ethyl ketone	15	15	15	2	10	10	10	1	0	0	0	0	0	0	0	0
Acetic acid	531	750	190	9	746	1200	420	7	773	1200	440	7	749	1200	400	7
n-Butanol	25	25	25	1	20	25	15	2	13	15	10	2	13	15	10	2
n-Pentanol	35	35	35	1	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene glycol	168	275	5	9	125	150	100	2	125	150	100	2	125	150	100	2
Hexanol	76	100	10	7	50	50	50	1	50	50	50	1	50	50	50	1
Isopentanol	263	300	175	6	100	100	100	1	100	100	100	1	100	100	100	1
Propionic acid	0	0	0	0	160	220	100	4	173	250	100	5	187	280	100	5
Butyric acid	0	0	0	0	144	225	50	5	132	220	45	5	166	250	50	5
Isobutyraldehyde	88	100	75	2	5	5	5	2	5	5	5	2	10	15	5	2
n-Butyraldehyde	58	100	15	2	15	15	15	1	13	15	10	2	18	25	10	2
C_5 acid	0	0	0	0	110	120	100	2	118	135	100	2	135	160	110	2
Isobutanol	82	120	75	3	5	5	5	1	5	5	5	1	5	5	5	1
Unknown	150	150	150	1	130	130	130	1	180	180	180	1	--	--	--	--

(a) Operating conditions for all filters:

Detention time - 3 days

Temperature - 34°C

Loading - 40 to 145 lb COD/1000 cu ft-day void volume

(b) Concentrations are as mg/l total carbon, for factor to convert to compound see Table 37.

(c) Average of 9 feed samples, 7 effluent samples, both composite and grab.

TABLE 39

EFFICIENCIES OF THREE PROCESSES IN SPECIFIC COMPOUND REMOVAL

	Anaerobic Lagoon			Anaerobic Filter	Contact Digester
	48 lb/1000 cu ft-day Loading	22 lb/1000 cu ft-day Loading	13 lb/1000 cu ft-day Loading	40-145 lb COD/ 1000 cu ft-day Loading	60-160 lb COD/ 1000 cu ft-day Loading
Carbon removal, %	32	37	47	31	18
Non-volatile acid carbon removal, %	66	69	58	63	73

SECTION XI

ECONOMIC ANALYSIS OF ALTERNATIVE ANAEROBIC PROCESSES

An economic study of the three anaerobic processes was made by a consulting engineering firm under a subcontract to this project. The alternatives considered included treatment of a dilute and concentrated feed (800 and 8,000 mg/liter BOD) of flow rates of 1 and 10 million gal/day for dilute waste water and 10 to 100 thousand gal/day for concentrated wastes. A summary of the wastewater flow and BOD concentration for each of the twelve design cases is shown in Table 40. The basic design parameters used in the comparison are listed in Table 41. A biochemical oxygen demand reduction of 50 and 80% was assumed, respectively, for dilute and concentrated wastes for all types of treatment. Estimates were based on laboratory data and were not necessarily confirmed by pilot studies. Assumptions made in developing the process designs are summarized in Table 42.

Anaerobic Processes

Estimates of the capital cost for the four design cases of each of the three anaerobic process alternatives are graphically presented in Figure 34. These costs are presented as unit capital costs ($/lb BOD_5 removed/day) in Figure 35. The cost estimates include equipment, materials, and labor costs for construction of the processes under consideration, but do not include certain project costs, such as costs for engineering or for a control building, which depend upon the type of additional facilities to be built as a part of the waste treatment system. The two more sophisticated processes (anaerobic filter and anaerobic contact) are much more costly than is the anaerobic lagoon process for both concentrated and dilute wastewaters.

Although annual operating costs were not estimated in this study for the individual anaerobic processes, the differences in these costs for the three anaerobic processes considered may be discussed in qualitative terms. Of the three processes, the anaerobic lagoon is the least expensive to operate since it requires no power, no operation as such, minimum lab analyses, and minimum maintenance. The anaerobic contact process is the most expensive to operate because it requires recycle and considerable analytical data to maintain a given level of treatment. Also, maintenance costs will be greater for this process, since it requires more mechanical equipment.

TABLE 40
SUMMARY OF WASTEWATER FLOWS AND BOD_5 CONCENTRATIONS FOR ECONOMIC COMPARISONS

	Case No.	Flow, gpd	BOD_5, mg/l
Anaerobic Filter Process			
Dilute Wastewater	1	10,000,000	800
	2	1,000,000	800
Concentrated Wastewater	3	100,000	8,000
	4	10,000	8,000
Anaerobic Contact Process			
Dilute Wastewater	5	10,000,000	800
	6	1,000,000	800
Concentrated Wastewater	7	100,000	8,000
	8	10,000	8,000
Anaerobic Lagoon			
Dilute Wastewater	9	10,000,000	800
	10	1,000,000	800
Concentrated Wastewater	11	100,000	8,000
	12	10,000	8,000

TABLE 41

DESIGN PARAMETERS FOR ECONOMIC COMPARISONS

	Dilute Wastewater	Concentrated Wastewater
BOD Loading (a) lb/1,000 cu ft/day		
Anaerobic Filter Process	47	210
Anaerobic Contact Process	31	100
Detention Time (a), days		
Anaerobic Lagoon Process	8	40
Treatment Temperature, °C		
Anaerobic Filter Process	20	35
Anaerobic Contact Process	20	35
Anaerobic Lagoon Process	20	20
BOD Removal, percent	50	80

(a) Based on influent flow.

TABLE 42

LIST OF MAJOR ASSUMPTIONS FOR ECONOMIC COMPARISONS

1. The wastewaters to be treated are not inhibitory.

2. Any pumping, pretreatment (e.g. neutralization, grit removal, equalization, or nutrient addition), or second-stage treatment should be comparable for the three alternatives; therefore, they need not be considered in this comparison.

3. The facilities are to be located in a warm climate such as in Texas, and the raw wastewater temperatures are assumed to be between 25 and 35°C.

4. Sulfates present in the wastewaters will be reduced to sulfides during anaerobic treatment. Some of the sulfides will be precipitated as heavy metal sulfides, thereby reducing toxicity attributable to the heavy metals. The remaining sulfides will be distributed between the liquid and gaseous phases as H_2S. It is assumed that no special problems will be caused by the hydrogen-sulfide in the digestion gas based on observations of no-odor problems during laboratory investigations.

FIGURE 34

CAPITAL COST ESTIMATES

ANAEROBIC TREATMENT PROCESSES

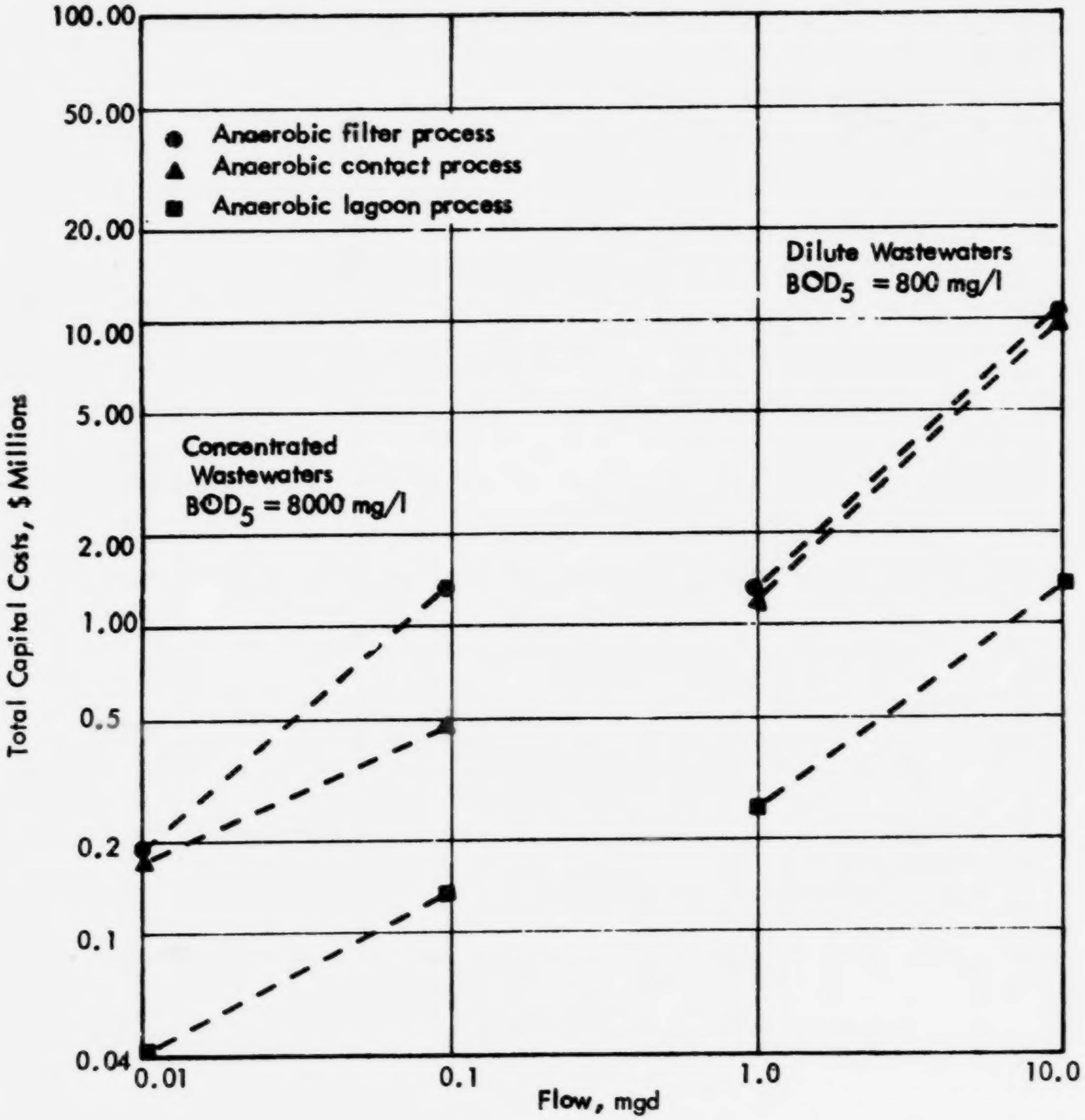
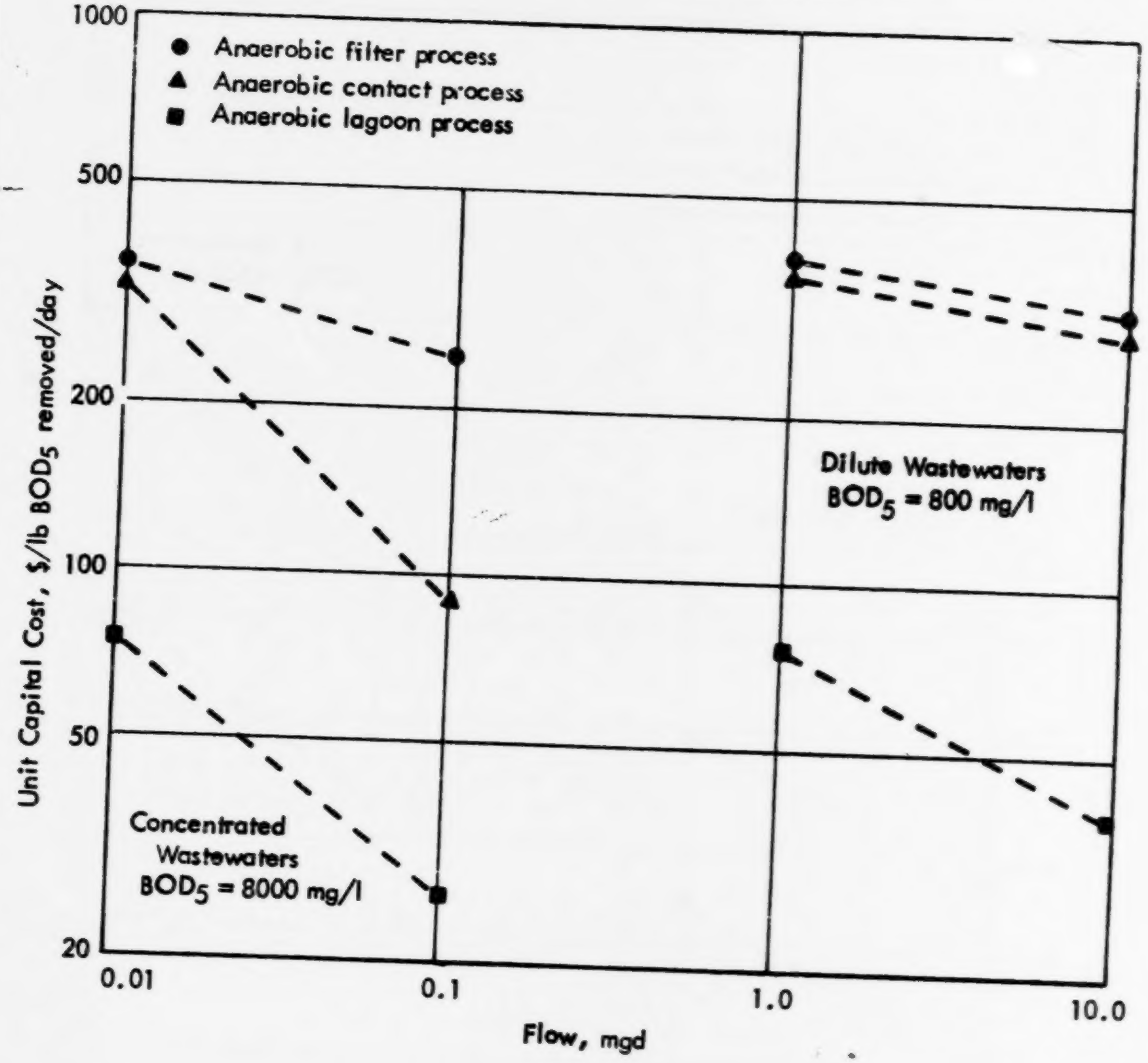


FIGURE 35
CAPITAL COST ESTIMATES
ANAEROBIC TREATMENT PROCESSES



SECTION XII

ACKNOWLEDGEMENTS

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SECTION XV

GLOSSARY

Aerobic Respiration - Biological oxidations in which molecular oxygen is the ultimate electron acceptor.

Aerobic Stabilization - Aerated biological process operated without solids sedimentation within process and without organism recycle.

Algae - Simple plants containing chlorophyll and capable of photosynthesis.

Anaerobic Respiration - Biological oxidations in which an inorganic compound other than molecular oxygen is the ultimate electron acceptor.

Areal Loading - Loading computed on the basis of weight organic applied per unit surface area per unit time.

BOD, BOD_5 - Five-day biochemical oxygen demand. Unless otherwise specified BOD indicates five-day BOD.

BOD_{20} - Long-term BOD exerted during 20 days' incubation.

BOD_T - Total BOD including that exerted by suspended solids; five-day incubation time unless otherwise specified.

BOD_F - Filtered BOD without suspended solids effect; five-day incubation time unless otherwise specified.

Biomass-Biosolids - Heterogeneous growth of bacteria, fungi, protozoa, and rotifers existing in biological treatment system.

COD_T - Total COD including that exerted by suspended solids.

COD_F - Filtered or soluble COD.

COD - Total Organic - COD which measures oxygen demand without sulfide influence.

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Concentrated Lagoon Effluent - A concentrated waste which has been previously treated in a full-scale anaerobic lagoon.

Concentrated Lagoon Feed - A concentrated waste stream (~15,000 mg/l COD).

Equalization - Mixing to provide a time smoothing of variation in a waste stream.

Facultative Lagoon - A lagoon which exists with an aerobic top and an anaerobic bottom layer.

Fermentation - Energy yielding biological oxidation-reduction reaction in which organic compounds serve as a final electron acceptor.

Hydraulic Retention Time (HRT) - Basin volume divided by liquid flow rate.

Metabolic Intermediates - Materials arising from formation or from breakdown of other materials in metabolism.

Methanogenic Bacteria - Obligately anaerobic bacteria characterized by an energy yielding metabolism which results in oxidation of simple organic materials and reduction of carbon dioxide or organics to methane.

Microaerophillic Bacteria - Bacteria which grow in the presence of minute quantities of free oxygen.

Non-Volatile Acid Organics - A measure of organics excluding volatile acids, computed as [Total Organic - Organic Contribution of Volatile Acids (as acetic)].

Photosynthesis - Utilization of light as an energy source through chlorophyll for biological synthesis, generally involving CO_2 fixation as a source of carbon.

Solids Retention Time (SRT) - Average retention time of microorganisms (Total Weight of Microorganisms/Total Weight of Solids Lost Daily)

Theoretical Oxygen Demand (TOD) - Theoretical amount of oxygen which would be required to convert the carbon and hydrogen in a compound to their highest oxidation state.

Thiorhodaceae - A family photosynthetic purple sulfur bacteria which anaerobically use carbon dioxide as a carbon source and hydrogen sulfide as a source of energy.

Volatile Acids - Short chain fatty acids detected by the column chromatographic method described in Standard Methods (21).

Volumetric Loading - Loading computed on the basis of weight organic per unit volume of reactor per unit of time.

APPENDIX I

PILOT PLANT OPERATING DATA

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FIGURE 36

ANAEROBIC LAGOON PERFORMANCE, AUGUST-SEPTEMBER 1970

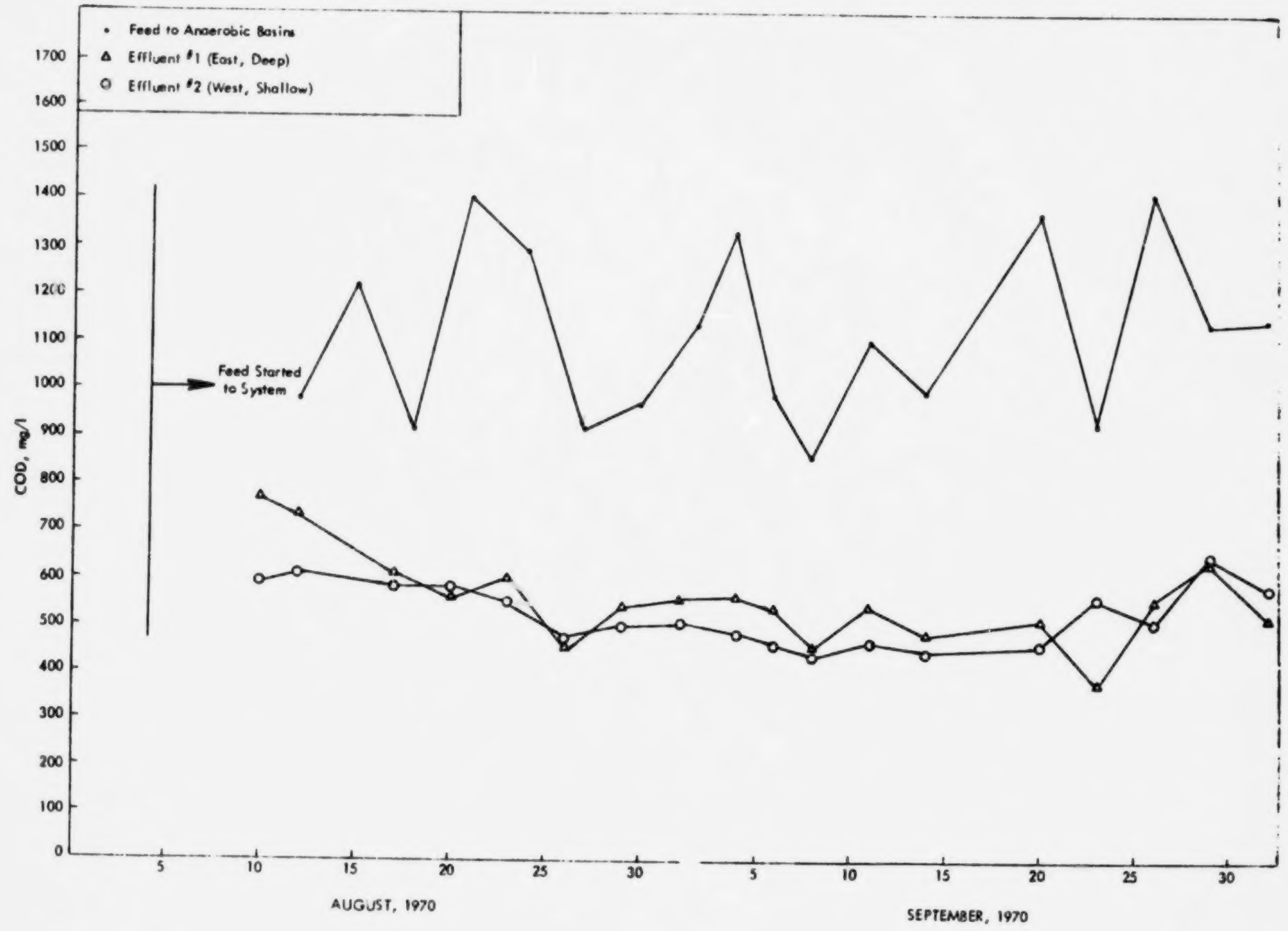

FIGURE 37

ANAEROBIC LAGOON PERFORMANCE, OCTOBER-DECEMBER 1970

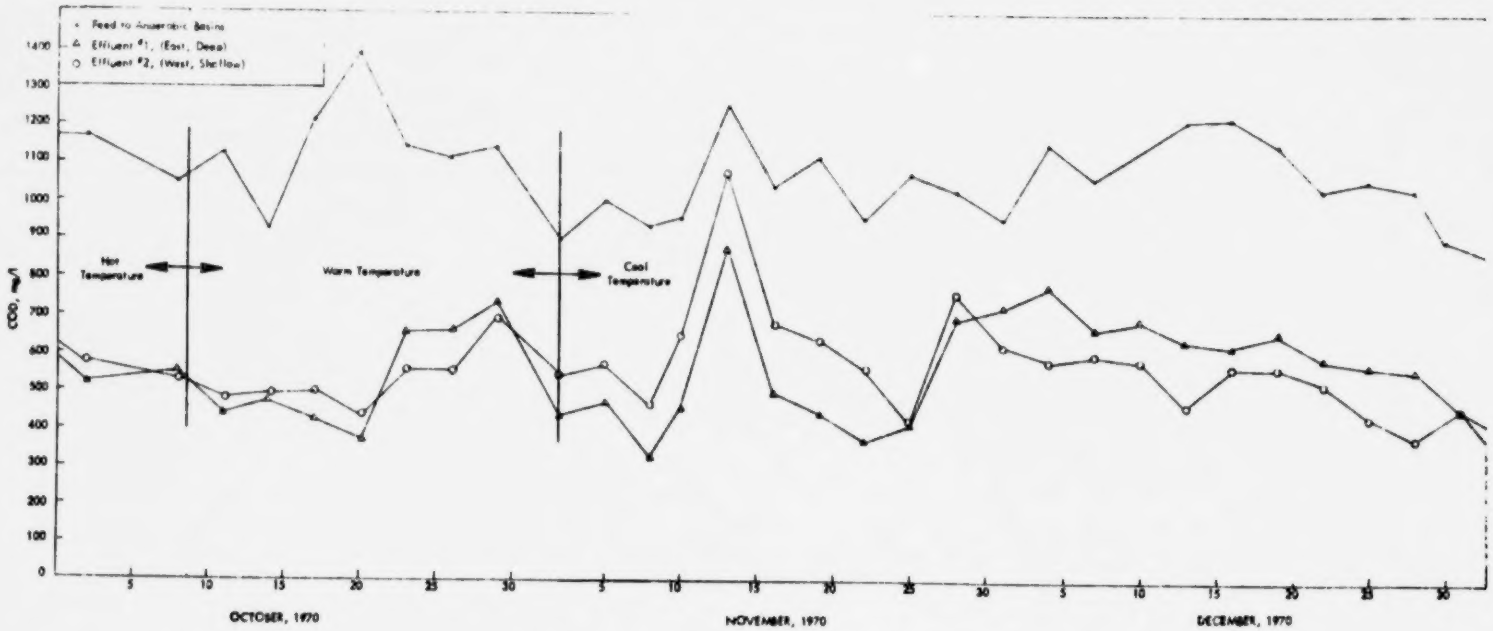

FIGURE 38

ANAEROBIC LAGOON PERFORMANCE, JANUARY-MARCH 1971

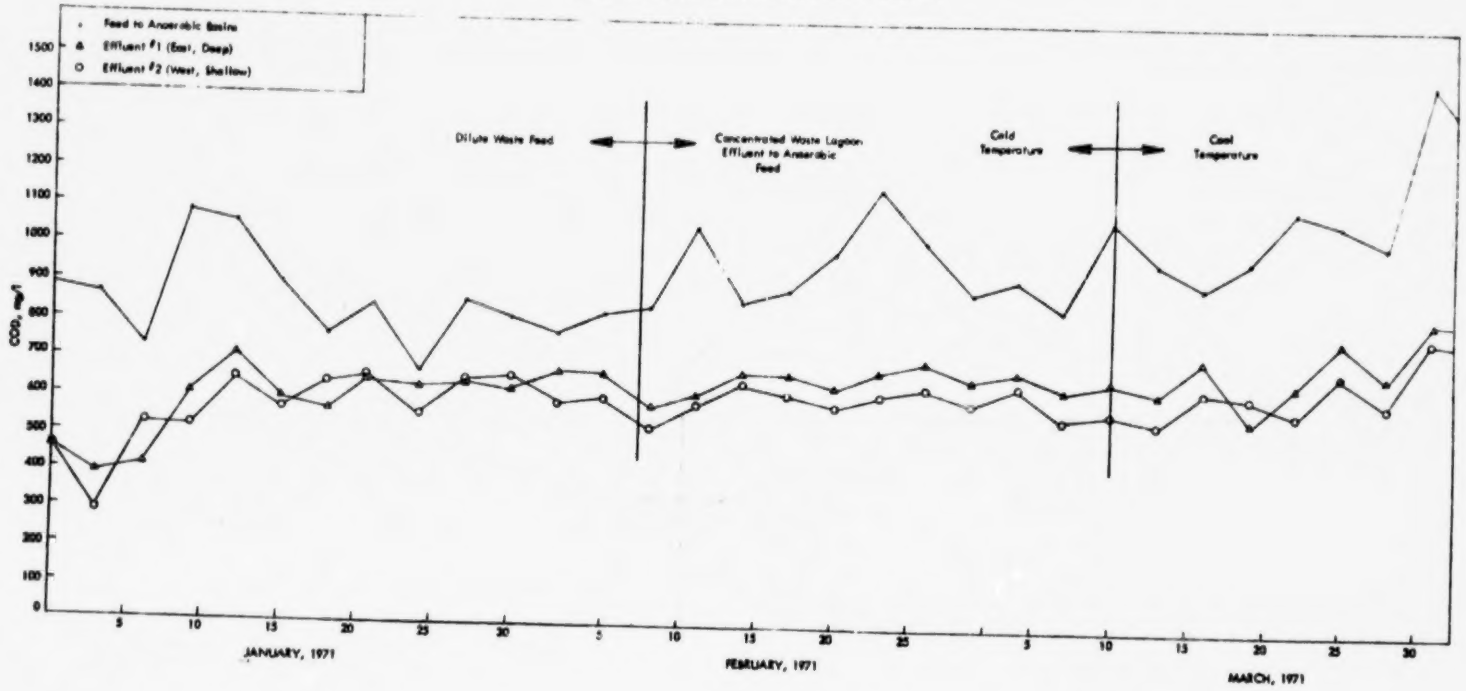

FIGURE 39

ANAEROBIC LAGOON PERFORMANCE, APRIL-JUNE 1971

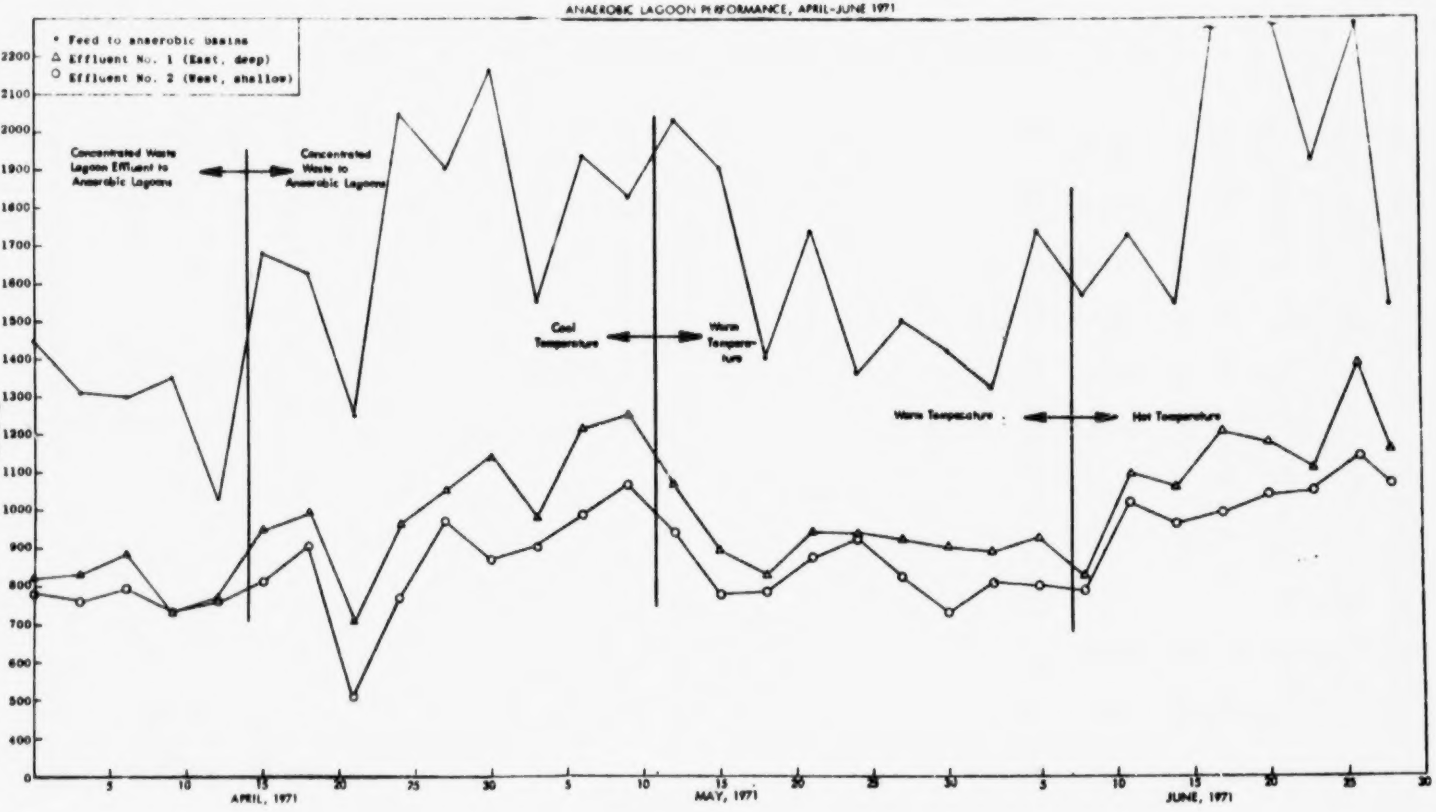

TABLE 43
ANAEROBIC LAGOON DATA

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1 (a)	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
10/ 1/70	7.6	7.7	26	26	--	--	--	--	—	580	--	--	--	--	--	580	--	--	--	--	--	580
2	7.8	7.8	28	28	1170	23	14	580	--	110	520/325 (b)	150	130	122	--	590	585/465(b)	156	134	195	--	700
3	7.6	7.8	29	29	--	--	--	--	--	120	--	--	--	--	--	580	--	--	--	--	--	700
4	7.4	7.7	29	29	--	--	--	-	--	360	--	--	--	--	--	600	--	--	--	--	--	680
5	7.4	7.8	28	28	--	--	--	440	105	380	--	--	--	184	230	660	--	--	--	138	240	720
6	7.5	7.7	29	29	--	--	--	--	--	250	--	--	--	--	--	670	--	--	--	--	--	740
7	7.5	7.9	29	29	--	--	--	--	--	120	--	--	--	--	--	670	--	--	--	--	--	740
8	7.4	7.8	28	28	1060	28	16	570	130	180	555/325	136	94	157	240	670	535/430	126	86	192	225	740
9	7.4	7.8	26	26	--	--	--	--	--	100	--	--	--	--	--	560	--	--	--	--	--	680
10	7.6	7.6	25	25	--	--	--	--	--	110	--	--	--	--	--	680	--	--	--	--	--	680
11	7.6	7.6	25	24	1125	42	17	500	105	180	440/305	72	48	140	250	700	480/370	70	48	160	210	660
12	7.4	7.4	24	24	--	--	--	--	--	210	--	--	--	--	--	520	--	--	--	--	--	610
13	7.4	7.6	25	25	--	--	--	--	--	320	--	--	--	--	--	550	--	--	--	--	--	580
14	7.4	7.5	26	26	925	59	35	420	110	180	475/315	77	63	102	230	500	590/360	59	39	114	200	560
15	7.2	7.4	25	25	--	--	--	--	--	200	--	--	--	--	--	480	--	--	--	--	--	580
16	7.2	7.4	25	25	--	--	--	--	--	180	--	--	--	--	--	510	--	--	--	--	--	560
17	7.4	7.8	25	25	1210	20	16	680	—	260	425/250	66	52	110	245	580	495/385	45	33	125	225	590
18	7.5	7.8	26	26	--	--	--	--	--	230	--	--	--	--	--	480	--	--	--	--	--	560
19	7.2	7.6	26	25	--	--	--	--	--	210	--	--	--	--	--	520	--	--	--	--	--	600
20	7.1	7.3	26	26	1390	37	27	800	190	80	370/290	74	57	100	275	510	435/355	77	57	134	265	680
21	7.1	7.5	26	26	--	--	--	--	--	120	--	--	--	--	--	560	--	--	--	--	--	690
22	7.1	7.5	26	26	--	--	--	--	--	145	--	--	--	--	--	570	--	--	--	--	--	690
23	7.3	7.6	26	26	1140	28	15	690	120	180	660/560	68	52	315	290	560	555/400	72	61	325	--	700
24	7.3	7.5	27	27	--	--	--	--	--	210	--	--	--	--	--	580	--	--	--	--	--	680
25	7.3	7.7	26	26	--	--	--	--	--	280	--	--	--	--	--	580	--	--	--	--	--	680
26	7.3	7.6	27	27	1110	30	41	442	108	260	66-/370	176	130	129	265	600	550/395	92	74	228	228	660
27	7.3	7.4	27	27	--	--	--	--	--	270	--	--	--	--	--	600	--	--	--	--	--	670
28	7.3	7.4	26	26	--	--	--	--	--	270	--	--	--	--	--	580	--	--	--	--	--	670
29	7.1	7.6	24	24	1140	36	17	451	120	220	735/435	88	61	144	—	540	695/435	76	54	—	--	680
30	7.5	7.8	23	23	--	--	--	--	--	220	--	--	--	--	--	600	--	--	--	--	--	690
31	7.0	7.6	24	24	--	--	--	--	--	220												

(continued)

(a) Number 1 Lagoon is 12 feet deep, Number 2 is 6 feet deep
(b) Total/Filtered
(c) Units are as in Table 7

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1 (a)	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
11/ 1/70	7.3	7.5	24	24	--	--	--	--	--	280	--	--	--	--	--	580	--	--	--	--	--	620
2	7.5	7.4	24	24	900	45	22	425	180	140	440/315	110	66	130	325	370	550/385	146	108	195	180	570
3	7.5	7.8	20	19	--	--	--	--	--	120	--	--	--	--	--	510	--	--	--	--	--	550
4	7.4	7.7	20	19	--	--	--	--	--	145	--	--	--	--	--	520	--	--	--	--	--	540
5	7.2	7.2	22	20	1005	--	--	420	120	160	475/345	106	68	145	265	580	585/495	117	88	210	90	500
6	7.1	7.3	19	21	--	--	--	--	--	280	--	--	--	--	--	500	--	--	--	--	--	520
7	7.1	7.3	19	21	--	--	--	--	--	200	--	--	--	--	--	510	--	--	--	--	--	580
8	7.1	7.3	20	23	940	142	112	455	228	210	330	70	46	92	120	500	470/	70	48	160		
9	7.4	7.4	22	22	--	--	--	--	--	180	--	--	--	--	--	560	--	--	--	--	--	
10	7.5	7.6	22	22	960	26	16	521	--	160	460/350	104	72	125	--	580	655/510	94	32	186	--	610
11	7.4	7.5	23	23	--	--	--	--	--	120	--	--	--	--	--	560	--	--	--	--	--	620
12	7.4	7.5	23	23	--	--	--	--	--	145	--	--	--	--	--	430	--	--	--	--	--	540
13	7.5	7.5	23	22	1260	39	20	590	--	200	885/600	82	54	186	--	450	1080/830	74	44	268	--	550
14	7.5	7.6	21	17	--	--	--	--	--	290	--	--	--	--	--	450	--	--	--	--	--	550
15	7.6	7.7	20	17	--	--	--	--	--	150	--	--	--	--	--	460	--	--	--	--	--	510
16	7.6	7.6	20	16	1040	52	20	410	--	190	505/415	72	42	114	--	450	685/500	76	42	169	--	460
17	7.4	7.5	20	17	--	--	--	--	--	130	--	--	--	--	--	450	--	--	--	--	--	510
18	7.4	7.6	20	17	--	--	--	--	--	120	--	--	--	--	--	510	--	--	--	--	--	590
19	7.4	7.3	21	18	1120	28	22	452	--	220	445/370	71	61	113	--	380	640/510	66	50	235	--	480
20	7.3	7.5	21	18	--	--	--	--	--	100	--	--	--	--	--	400	--	--	--	--	--	480
21	7.2	7.4	21	19	--	--	--	--	--	120	--	--	--	--	--	410	--	--	--	--	--	490
22	7.4	7.6	22	20	955	32	18	380	110	130	375/295	78	38	135	260	480	565/530	82	46	134	215	610
23	7.4	7.3	22	20	--	--	--	--	--	200	--	--	--	--	--	330	--	--	--	--	--	620
24	7.3	7.4	18	16	--	--	--	--	--	480	--	--	--	--	--	340	--	--	--	--	--	620
25	7.4	7.0	18	16	1075	21	14	610	96	210	415/305	84	68	151	60	380	420/385	68	50	165	84	610
26	7.1	7.0	18	17	--	--	--	--	--	100	--	--	--	--	--	300	--	--	--	--	--	380
27	7.0	7.3	20	18	--	--	--	--	--	92	--	--	--	--	--	280	--	--	--	--	--	360
28	7.1	7.3	21	19	1030	52	20	410	--	110	695/-	54	22	230	--	300	760/620	58	32	240	--	380
29	7.1	7.3	21	19	--	--	--	--	--	120	--	--	--	--	--	310	--	--	--	--	--	380
30	7.2	7.3	21	19	--	--	--	--	--	180	--	--	--	--	--	360	--	--	--	--	--	400

(continued)

(a) Number 1 Lagoon is 12 feet deep, Number 2 is 6 feet deep.

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.
12/ 1/70	7.1	7.4	21	20	965	48	30	527	--	160	735/675	64	40	202	--	360	630/530	58	34	219	--	420
2	7.0	7.4	22	21	--	--	--	--	--	160	--	--	--	--	--	340	--	--	--	--	--	410
3	7.0	7.3	22	21	--	--	--	--	--	200	--	--	--	--	--	380	--	--	--	--	--	400
4	7.2	7.5	22	21	1160	36	18	660	--	200	785/695	66	30	246	--	380	590/480	88	44	255	--	590
5	7.2	7.5	22	21	--	--	--	--	--	70	--	--	--	--	--	380	--	--	--	--	--	610
6	7.0	7.2	21	19	--	--	--	--	--	44	--	--	--	--	--	400	--	--	--	--	--	480
7	7.3	7.5	20	18	1070	68	24	652	--	250	675/630	64	20	201	--	490	605/515	60	28	203	--	600
8	7.4	7.6	19	18	--	--	--	--	--	210	--	--	--	--	--	480	--	--	--	--	--	650
9	7.3	7.6	21	20	--	--	--	--	--	180	--	--	--	--	--	450	--	--	--	--	--	650
10	7.3	7.6	21	20	1140	72	28	637	--	200	695/610	84	44	283	--	460	590/495	80	40	292	--	560
11	7.1	7.4	19	18	--	--	--	--	--	180	--	--	--	--	--	480	--	--	--	--	--	550
12	7.2	7.4	18	18	--	--	--	--	--	210	--	--	--	--	--	500	--	--	--	--	--	540
13	7.1	7.4	17	16	1220	56	12	390	--	260	645/545	104	36	198	--	520	465/400	88	40	170	--	580
14	7.1	7.4	17	16	--	--	--	--	--	200	--	--	--	--	--	520	--	--	--	--	--	580
15	7.2	7.4	17	16	--	--	--	--	--	100	--	--	--	--	--	540	--	--	--	--	--	560
16	7.1	7.4	18	17	1230	72	32	687	--	110	630/610	104	56	272	--	520	570/460	96	52	250	--	550
17	7.2	7.3	18	17	--	--	--	--	--	350	--	--	--	--	--	530	--	--	--	--	--	550
18	7.2	7.4	18	17	--	--	--	--	--	260	--	--	--	--	--	580	--	--	--	--	--	580
19	7.2	7.4	22	21	1160	58	22	575	--	320	665/590	72	42	250	--	570	570/475	78	50	150	--	590
20	7.4	7.6	24	23	--	--	--	--	--	150	--	--	--	--	--	530	--	--	--	--	--	620
21	7.2	7.4	24	23	--	--	--	--	--	260	--	--	--	--	--	560	--	--	--	--	--	580
22	7.4	7.7	24	23	1040	72	58	480	180	200	595/540	90	58	188	250	540	565/480	92	72	176	230	550
23	7.4	7.7	23	22	--	--	--	--	--	200	--	--	--	--	--	570	--	--	--	--	--	10
24	7.2	7.5	19	18	--	--	--	--	--	220	--	--	--	--	--	480	--	--	--	--	--	490
25	7.2	7.4	20	19	1060	46	24	535	--	120	575/490	70	48	172	--	500	435/365	80	60	126	--	520
26	7.2	7.7	18	18	--	--	--	--	--	240	--	--	--	--	--	480	--	--	--	--	--	500
27	7.2	7.6	20	20	--	--	--	--	--	210	--	--	--	--	--	460	--	--	--	--	--	570
28	7.2	7.5	20	20	1040	64	38	480	--	210	565/490	82	57	150	132	460	385/330	86	54	114	108	580
29	7.2	7.5	22	22	--	--	--	--	--	120	--	--	--	--	--	480	--	--	--	--	--	560
30	7.2	7.5	22	22	--	--	--	--	--	140	--	--	--	--	--	500	--	--	--	--	--	560
31	7.3	7.6	19	19	905	52	40	--	--	160	460/380	74	--	--	--	500	460/345	94	62	--	--	570

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
1/ 1/71	7.3	7.7	18	18	--	--	--	--	--	100	--	--	--	--	--	510	--	--	--	--	--	610
2	7.2	7.4	19	19	--	--	--	--	--	120	--	--	--	--	--	500	--	--	--	--	--	520
3	7.3	7.3	18	18	865	48	30	462	--	140	395/345	68	40	126	--	510	290/215	72	44	99	--	480
4	7.3	7.3	17	17	--	--	--	--	--	150	--	--	--	--	--	510	--	--	--	--	--	410
5	7.7	7.5	14	14	--	--	--	--	--	50	--	--	--	--	--	550	--	--	--	--	--	450
6	7.6	7.3	10	10	735	36	20	392	144	120	415/405	48	26	154	144	530	525/455	64	40	152	180	450
7	7.6	8.2	9	9	--	--	--	--	--	160	--	--	--	--	--	530	--	--	--	--	--	550
8	7.5	7.7	13	9	--	--	--	--	--	200	--	--	--	--	--	570	--	--	--	--	--	500
9	7.5	7.8	13	10	1080	50	30	532	192	160	605/530	64	36	168	--	540	520/470	56	30	165	185	490
10	7.1	7.3	15	14	--	--	--	--	--	230	--	--	--	--	--	510	--	--	--	--	--	510
11	7.1	7.3	18	17	--	--	--	--	--	Nil	--	--	--	--	--	510	--	--	--	--	--	530
12	7.1	7.2	19	19	1055	56	16	440	152	Nil	715/665	70	34	180	150	490	548/590	70	36	148	190	490
13	7.2	7.3	21	20	--	--	--	--	--	260	--	--	--	--	--	480	--	--	--	--	--	530
14	7.3	7.3	21	21	--	--	--	--	--	150	--	--	--	--	--	500	--	--	--	--	--	420
15	7.4	7.2	20	20	895	42	18	459	--	100	595/535	70	28	186	--	510	570/505	60	26	171	--	410
16	7.5	7.1	19	19	--	--	--	--	--	185	--	--	--	--	--	530	--	--	--	--	--	400
17	7.5	7.2	20	19	--	--	--	--	--	140	--	--	--	--	--	530	--	--	--	--	--	410
18	7.4	7.2	20	19	765	44	30	330	--	100	570/560	58	36	162	--	510	640/620	62	38	276	--	400
19	7.3	7.3	19	18	--	--	--	--	--	150	--	--	--	--	--	380	--	--	--	--	--	420
20	7.2	7.3	20	19	--	--	--	--	--	120	--	--	--	--	--	380	--	--	--	--	--	420
21	7.1	7.3	20	20	840	44	34	350	--	150	645/605	56	42	131	--	350	655/565	62	46	207	--	370
22	7.2	7.2	20	20	--	--	--	--	--	180	--	--	--	--	--	380	--	--	--	--	--	290
23	7.2	7.2	20	19	--	--	--	--	--	160	--	--	--	--	--	390	--	--	--	--	--	420
24	7.2	7.2	20	19	670	42	26	345	--	140	630/545	40	26	206	--	400	555/470	42	26	148	--	410
25	7.0	7.0	20	20	--	--	--	--	--	140	--	--	--	--	--	350	--	--	--	--	--	270
26	6.8	6.9	22	21	--	--	--	--	--	100	--	--	--	--	--	350	--	--	--	--	--	300
27	6.5	6.7	19	18	855	38	26	450	110	100	635/570	54	38	222	260	360	650/590	38	24	216	245	300
28	6.9	7.0	20	19	--	--	--	--	--	210	--	--	--	--	--	340	--	--	--	--	--	330
29	7.0	7.1	21	20	--	--	--	--	--	230	--	--	--	--	--	380	--	--	--	--	--	330
30	6.9	7.0	22	21	810	36	2	442	180	130	625/545	42	38	274	202	340	655/595	34	22	220	192	310
31	7.2	7.2	22	21	--	--	--	--	--	210	--	--	--	--	--	410	--	--	--	--	--	400

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.
2/ 1/71	7.2	7.2	19	18	--	--	--	--	--	220	--	--	--	--	--	400	--	--	--	--	--	390
2	7.6	7.6	17	16	785	40	20	442	--	380	615/590	42	32	219	--	440	600/555	32	24	204	--	400
3	7.6	7.6	19	18	--	--	--	--	--	190	--	--	--	--	--	450	--	--	--	--	--	380
4	7.4	7.5	19	19	--	--	--	--	--	200	--	--	--	--	--	400	--	--	--	--	--	360
5	7.5	7.4	18	17	835	36	22	320	--	260	680/635	48	34	259	--	360	615/580	34	22	223	--	340
6	7.2	7.3	18	17	--	--	--	--	--	460	--	--	--	--	--	430	--	--	--	--	--	360
7	7.1	7.0	17	16	--	--	--	--	--	Nil	--	--	--	--	--	450	--	--	--	--	--	370
8	6.5	6.4	14	13	855	50	40	265	--	Nil	595/555	78	64	202	--	410	535/490	68	52	214	--	310
9	6.6	6.5	14	13	--	--	--	--	--	400	--	--	--	--	--	400	--	--	--	--	--	350
10	6.9	6.8	15	14	--	--	--	--	--	390	--	--	--	--	--	460	--	--	--	--	--	380
11	7.0	7.0	15	14	1070	48	28	405	--	120	630/605	40	26	262	--	480	300/565	48	30	259	--	400
12	7.1	7.0	16	15	--	--	--	--	--	180	--	--	--	--	--	480	--	--	--	--	--	420
13	7.1	7.2	16	16	--	--	--	--	--	280	--	--	--	--	--	460	--	--	--	--	--	430
14	7.1	7.2	15	15	870	42	30	375	108	410	685/645	62	48	140	180	485	655/610	54	52	138	156	440
15	7.1	7.2	14	15	--	--	--	--	--	450	--	--	--	--	--	400	--	--	--	--	--	370
16	7.0	7.0	20	19	--	--	--	--	--	480	--	--	--	--	--	380	--	--	--	--	--	370
17	6.9	6.9	21	20	900	80	56	392	--	430	680/660	62	40	120	--	340	630/575	76	28	102	--	330
18	6.9	7.0	21	20	--	--	--	--	--	450	--	--	--	--	--	360	--	--	--	--	--	360
19	7.0	7.1	22	21	--	--	--	--	--	400	--	--	--	--	--	370	--	--	--	--	--	380
20	6.9	7.0	22	21	1000	48	30	352	--	320	645/620	46	30	168	--	340	593/575	80	62	168	--	340
21	6.9	7.0	20	19	--	--	--	--	--	220	--	--	--	--	--	360	--	--	--	--	--	380
22	6.9	7.0	18	17	--	--	--	--	--	400	--	--	--	--	--	380	--	--	--	--	--	380
23	7.0	7.2	17	15	1170	69	48	412	132	550	690	50	38	219	420	400	625/	50	40	172	398	410
24	7.1	7.3	17	16	--	--	--	--	--	370	--	--	--	--	--	400	--	--	--	--	--	400
25	7.1	7.3	19	18	--	--	--	--	--	400	--	--	--	--	--	400	--	--	--	--	--	430
26	7.0	7.3	18	15	1030	47	37	415	144	390	715/	60	38	198	205	390	645/	56	38	178	192	360
27	6.9	7.1	19	17	--	--	--	--	--	140	--	--	--	--	--	370	--	--	--	--	--	360
28	6.9	7.0	21	20	--	--	--	--	--	80	--	--	--	--	--	360	--	--	--	--	--	360

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.
3/ 1/71	7.0	7.1	22	21	856	48	32	367	--	240	660/585	68	36	188	--	350	595/550	82	58	160	--	350
2	6.7	6.8	22	21	--	--	--	--	--	280	--	--	--	--	--	340	--	--	--	--	--	340
3	7.1	7.2	14	19	--	--	--	--	--	450	--	--	--	--	--	370	--	--	--	--	--	390
4	7.1	7.2	13	12	925	44	32	492	208	450	600/652	68	56	208	208	370	645/540	78	44	169	157	370
5	7.0	6.9	12	11	--	--	--	--	--	350	--	--	--	--	--	380	--	--	--	--	--	380
6	6.9	7.0	14	13	--	--	--	--	--	400	--	--	--	--	--	380	--	--	--	--	--	410
7	7.0	7.1	16	15	845	46	32	532	157	360	635/555	50	38	273	157	410	655/515	50	18	286	208	420
8	7.1	7.2	18	17	--	--	--	--	--	400	--	--	--	--	--	450	--	--	--	--	--	450
9	7.2	7.4	18	17	--	--	--	--	--	440	--	--	--	--	--	450	--	--	--	--	--	450
10	7.0	7.2	19	18	1080	34	28	582	208	410	600/605	36	30	312	220	460	575/525	40	34	266	220	450
11	7.0	7.1	20	19	--	--	--	--	--	430	--	--	--	--	--	450	--	--	--	--	--	450
12	7.0	7.2	21	20	--	--	--	--	--	460	--	--	--	--	--	440	--	--	--	--	--	450
13	7.0	7.0	22	20	970	56	34	530	208	390	650/575	72	50	231	372	370	550/490	76	54	162	312	380
14	6.9	7.1	24	23	--	--	--	--	--	400	--	--	--	--	--	450	--	--	--	--	--	450
15	6.9	7.0	22	20	--	--	--	--	--	170	--	--	--	--	--	440	--	--	--	--	--	430
16	6.8	7.0	23	21	910	54	30	455	216	410	715/625	70	50	264	276	420	635/520	100	78	262	264	440
17	6.1	7.0	25	24	--	--	--	--	--	400	--	--	--	--	--	410	--	--	--	--	--	430
18	7.2	7.3	21	23	--	--	--	--	--	390	--	--	--	--	--	450	--	--	--	--	--	460
19	7.1	7.0	18	20	980	48	38	400	144	350	560/540	44	38	303	228	480	620/550	84	74	240	180	500
20	7.1	7.3	18	17	--	--	--	--	--	280	--	--	--	--	--	500	--	--	--	--	--	560
21	7.3	7.4	20	17	--	--	--	--	--	640	--	--	--	--	--	560	--	--	--	--	--	580
22	7.3	7.2	22	19	1115	58	46	415	144	400	655/585	44	36	182	144	500	575/	60	48	174	192	530
23	7.3	7.5	21	21	--	--	--	--	--	480	--	--	--	--	--	480	--	--	--	--	--	490
24	7.2	7.4	18	17	--	--	--	--	--	380	--	--	--	--	--	540	--	--	--	--	--	560
25	7.2	7.4	19	18	1080	46	30	365	216	410	770/705	38	28	246	216	540	680/590	50	38	189	204	560
26	7.3	7.5	17	16	--	--	--	--	--	470	--	--	--	--	--	600	--	--	--	--	--	510
27	7.2	7.4	21	20	--	--	--	--	--	400	--	--	--	--	--	570	--	--	--	--	--	600
28	7.2	7.7	22	21	1020	44	22	666	264	300	675/600	40	38	262	288	600	600/520	46	44	247	240	600
29	7.1	7.2	23	22	--	--	--	--	--	580	--	--	--	--	--	590	--	--	--	--	--	600
30	7.4	7.6	20	19	--	--	--	--	--	420	--	--	--	--	--	610	--	--	--	--	--	610
31	7.3	7.4	22	21	1450	54	32	710	180	--	820/735	58	42	303	96	610	775/650	70	52	279	120	620

ANAEROBIC LAGOON DATA

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
4/ 1/71	7.3	7.5	21	20	--	--	--	--	--	380	--	--	--	--	--	630	--	--	--	--	--	660
2	7.3	7.5	19	19	--	--	--	--	--	520	--	--	--	--	--	750	--	--	--	--	--	730
3	7.4	7.5	18	17	1310	60	38	775	252	120	830/715	76	60	366	228	760	760/580	76	60	240	264	810
4	7.3	7.5	18	17	--	--	--	--	--	480	--	--	--	--	--	800	--	--	--	--	--	780
5	7.2	7.3	19	18	--	--	--	--	--	280	--	--	--	--	--	780	--	--	--	--	--	680
6	7.2	7.6	19	17	1300	56	40	610	240	540	885/780	58	46	372	288	770	795/715	56	44	300	276	720
7	7.2	7.3	18	16	--	--	--	--	--	800	--	--	--	--	--	800	--	--	--	--	--	740
8	7.3	7.4	21	19	--	--	--	--	--	300	--	--	--	--	--	780	--	--	--	--	--	750
9	7.2	7.3	21	20	1350/1260	58	54	627	288	400	730/890	52	40	319	312	800	715/595	70	58	271	252	750
10	7.2	7.4	22	21	--	--	--	--	--	250	--	--	--	--	--	750	--	--	--	--	--	730
11	7.8	7.8	22	21	--	--	--	--	--	290	--	--	--	--	--	740	--	--	--	--	--	740
12	7.4	7.6	22	21	1030/945	58	42	502	192	250	770/765	76	58	284	228	740	660/590	66	56	166	168	740
13	7.4	7.6	23	21	--	--	--	--	--	250	--	--	--	--	--	730	--	--	--	--	--	730
14	6.8	7.0	23	21	--	--	--	--	--	Nil	--	--	--	--	--	600	--	--	--	--	--	620
15	7.0	7.1	24	23	1680	86	78	580	--	260	950/	60	40	292	--	610	810	82	62	219	--	640
16	7.1	7.3	23	22	--	--	--	--	--	560	--	--	--	--	--	650	--	--	--	--	--	750
17	7.2	7.4	23	22	--	--	--	--	--	340	--	--	--	--	--	680	--	--	--	--	--	760
18	7.2	7.4	23	22	1630	56	45	567	215	380	995	72	60	303	230	680	905	96	86	278	170	770
19	7.6	7.8	23	22	--	--	--	--	--	530	--	--	--	--	--	730	--	--	--	--	--	760
20	7.6	7.8	23	22	--	--	--	--	--	370	--	--	--	--	--	680	--	--	--	--	--	700
21	7.5	7.5	24	24	1250	66	44	477	252	360	705/565	60	52	[illegible]	192	670	505/465	56	50	146	192	700
22	7.5	7.5	22	22	--	--	--	--	--	360	--	--	--	--	--	670	--	--	--	--	--	700
23	7.5	7.8	24	23	--	--	--	--	--	450	--	--	--	--	--	730	--	--	--	--	--	730
24	7.4	7.4	26	24	2050	68	42	612	445	340	960/780	58	46	306	336	790	765/720	52	46	286	324	740
25	7.4	7.5	25	24	--	--	--	--	--	430	--	--	--	--	--	860	--	--	--	--	--	750
26	7.3	7.4	25	24	--	--	--	--	--	480	--	--	--	--	--	820	--	--	--	--	--	820
27	7.5	7.6	26	24	1900	68	42	672	418	450	1055/955	60	38	432	396	860	970/830	68	48	324	118	800
28	7.5	7.6	25	24	--	--	--	--	--	400	--	--	--	--	--	850	--	--	--	--	--	830
29	7.4	7.6	24	24	--	--	--	--	--	450	--	--	--	--	--	890	--	--	--	--	--	860
30	7.5	7.6	24	23	2160	66	46	--	384	470	1140/1000	62	52	--	336	870	870/825	68	56	--	348	840

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
5/ 1/71	7.3	7.4	24	23	--	--	--	--	--	200	--	--	--	--	--	860	--	--	--	--	--	820
2	7.2	7.3	24	23	--	--	--	--	--	280	--	--	--	--	--	840	--	--	--	--	--	860
3	7.2	7.5	24	23	1550	60	40	730	300	450	975/890	70	58	532	324	690	900/865	56	44	297	420	780
4	7.1	7.4	25	26	--	--	--	--	--	480	--	--	--	--	--	720	--	--	--	--	--	820
5	7.1	7.3	26	25	--	--	--	--	--	--	--	--	--	--	--	750	--	--	--	--	--	750
6	7.4	7.1	26	25	1940	86	48	860	468	600	1220/1170	78	54	561	560	800	990/910	66	50	310	516	870
7	7.2	7.6	26	25	--	--	--	--	--	390	--	--	--	--	--	790	--	--	--	--	--	820
8	7.2	7.5	26	25	--	--	--	--	--	400	--	--	--	--	--	740	--	--	--	--	--	880
9	7.2	7.6	24	25	1835	84	50	Broke	396	340	1255/1075	68	52	Broke	494	840	1070/950	64	50	Broke	386	900
10	7.2	7.6	25	26	--	--	--	--	--	630	--	--	--	--	--	840	--	--	--	--	--	880
11	7.5	7.6	24	26	--	--	--	--	--	360	--	--	--	--	--	860	--	--	--	--	--	890
12	7.3	7.7	25	26	2040	72	52	Broke	445	900	1070/970	84	74	Broke	448	900	940/865	66	56	Broke	445	900
13	7.5	7.6	25	26	--	--	--	--	--	410	--	--	--	--	--	900	--	--	--	--	--	860
14	7.5	7.5	26	27	--	--	--	--	--	530	--	--	--	--	--	910	--	--	--	--	--	900
15	7.5	7.2	26	27	1910	72	56	990	--	400	895/850	90	78	429	--	900	775/735	62	44	427	--	910
16	7.4	7.5	26	27	--	--	--	--	--	280	--	--	--	--	--	900	--	--	--	--	--	910
17	7.2	7.0	26	29	--	--	--	--	--	480	--	--	--	--	--	800	--	--	--	--	--	820
18	7.0	7.2	27	27	1400	74	60	610	288	510	830/675	74	64	360	288	820	785/790	60	52	364	288	830
19	7.1	7.1	27	27	--	--	--	--	--	500	--	--	--	--	--	800	--	--	--	--	--	840
20	6.7	6.9	26	26	--	--	--	--	--	430	--	--	--	--	--	790	--	--	--	--	--	780
21	6.4	7.0	26	26	1740	114	84	810	372	480	945/910	66	58	370	456	880	875/830	70	60	344	408	900
22	6.7	6.3	25	25	--	--	--	--	--	650	--	--	--	--	--	850	--	--	--	--	--	860
23	6.2	6.5	27	27	--	--	--	--	--	520	--	--	--	--	--	780	--	--	--	--	--	800
24	6.9	6.8	27	27	1360	102	80	555	288	500	940/800	52	44	371	468	750	920/770	52	50	309	480	800
25	6.8	7.1	27	27	--	--	--	--	--	640	--	--	--	--	--	770	--	--	--	--	--	810
26	7.2	7.5	27	27	--	--	--	--	--	490	--	--	--	--	--	760	--	--	--	--	--	780
27	7.4	7.6	27	27	1500	62	52	765	324	420	925/895	50	42	396	492	800	825/805	54	50	336	468	760
28	7.4	7.6	27	27	--	--	--	--	--	300	--	--	--	--	--	800	--	--	--	--	--	780
29	7.2	7.4	27	27	--	--	--	--	--	280	--	--	--	--	--	780	--	--	--	--	--	780
30	7.2	7.4	27	27	1420	50	40	730	--	580	905/843	60	50	545	--	780	730/710	72	62	450	--	740
31	7.2	7.5	27	27	--	--	--	--	--	540	--	--	--	--	--	780	--	--	--	--	--	800

(continued)

AERATED STABILIZATION DATA (continued)

	Basin Conditions			Feed				Effluent			
Day	pH	Temp., °C	D.O.(b)	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
11/ 1/70	7.8	20	1.8	--	--	--	--	--	--	--	55
2	7.8	19	1.2	440/315	110	66	130	438/210	--	--	62
3	7.6	19	0.8	--	--	--	--	445/300	--	--	71
4	7.7	18	1.8	--	--	--	--	420/310	--	--	92
5	7.7	15	0.5	475/345	106	68	145	390/205	--	--	80
6	7.6	14	1.4	--	--	--	--	335/195	156	118	64
7	7.2	15	0.8	--	--	--	--	410/295	148	102	59
8	7.6	20	0.5	330/-	70	46	92	390/310	188	100	62
9	7.3	21	1.8	--	--	--	--	395/320	240	124	70
10	7.6	18	2.0	464/350	104	72	125	360/235	126	32	66
11	7.6	20	1.0	--	--	--	--	350/250	156	122	61
12	7.6	19	0.3	--	--	--	--	295/225	142	100	107
13	7.3	17	0.7	885/600	82	54	186	345/315	140	60	71
14	7.7	16	1.6	--	--	--	--	670/440	106	76	118
15	7.7	14	0.6	--	--	--	--	745/490	94	66	144
16	7.7	13	0.8	505/415	72	42	114	555/390	96	68	132
17	7.8	14	0.8	--	--	--	--	495/365	118	80	140
18	7.8	16	0.4	--	--	--	--	360/117	118	86	132
19	7.6	18	0.8	445/370	71	61	113	410/270	116	90	96
20	7.3	18	0.8	--	--	--	--	560/	--	--	212
21	7.4	18	0.4	--	--	--	--	530/380	--	--	50
22	7.6	18	1.2	375/295	78	38	135	430/395	130	84	40
23	7.5	17	3.8	--	--	--	--	415/295	132	86	56
24	7.6	14	0.8	--	--	--	--	525/390	106	76	90
25	7.6	14	6.4	415/305	84	68	151	595/375	98	74	76
26	7.4	16	7.6	--	--	--	--	386/288	94	82	66
27	7.3	18	6.8	--	--	--	--	340/330	102	80	81
28	7.4	20	7.4	695/-	54	22	230	330/292	47	34	60
29	7.6	20	7.6	--	--	--	--	300/260	88	62	66
30	7.6	20	8.0	--	--	--	--	--	--	--	56

(b) All units mg/l.

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.	COD	TSS	VSS	BOD$_5$	VA	Alk.
5/ 1/71	7.3	7.4	24	23	--	--	--	--	--	200	--	--	--	--	--	860	--	--	--	--	--	820
2	7.2	7.3	24	23	--	--	--	--	--	280	--	--	--	--	--	840	--	--	--	--	--	840
3	7.2	7.5	24	23	1550	60	40	730	300	450	975/890	70	58	532	324	690	900/865	56	44	297	420	780
4	7.1	7.4	25	26	--	--	--	--	--	480	--	--	--	--	--	720	--	--	--	--	--	820
5	7.1	7.3	25	25	--	--	--	--	--	--	--	--	--	--	--	750	--	--	--	--	--	750
6	7.4	7.1	26	25	1940	86	48	860	468	600	1220/1170	78	54	561	560	800	990/910	66	50	310	516	870
7	7.2	7.6	26	25	--	--	--	--	--	390	--	--	--	--	--	790	--	--	--	--	--	820
8	7.2	7.5	26	25	--	--	--	--	--	400	--	--	--	--	--	740	--	--	--	--	--	880
9	7.2	7.6	24	25	1835	84	50	Broke	396	340	1255/1075	68	52	Broke	494	840	1070/950	64	50	Broke	386	900
10	7.2	7.6	25	26	--	--	--	--	--	630	--	--	--	--	--	840	--	--	--	--	--	880
11	7.5	7.6	24	26	--	--	--	--	--	360	--	--	--	--	--	860	--	--	--	--	--	890
12	7.3	7.7	25	26	2040	72	52	Broke	445	900	1070/970	84	74	Broke	448	900	940/865	66	56	Broke	445	900
13	7.5	7.6	25	26	--	--	--	--	--	410	--	--	--	--	--	900	--	--	--	--	--	860
14	7.5	7.5	26	27	--	--	--	--	--	530	--	--	--	--	--	910	--	--	--	--	--	900
15	7.5	7.2	26	27	1910	72	56	990	--	400	895/850	90	78	429	--	900	775/735	62	44	427	--	910
16	7.4	7.5	26	27	--	--	--	--	--	280	--	--	--	--	--	900	--	--	--	--	--	910
17	7.2	7.0	26	29	--	--	--	--	--	480	--	--	--	--	--	800	--	--	--	--	--	820
18	7.0	7.2	27	27	1400	74	60	610	288	510	830/675	74	64	360	288	820	785/790	60	52	364	288	830
19	7.1	7.1	27	27	--	--	--	--	--	500	--	--	--	--	--	800	--	--	--	--	--	840
20	6.7	6.9	26	26	--	--	--	--	--	430	--	--	--	--	--	790	--	--	--	--	--	780
21	6.4	7.0	26	26	1740	114	84	810	372	480	945/910	66	58	370	456	880	875/830	70	60	344	408	900
22	6.7	6.3	25	25	--	--	--	--	--	650	--	--	--	--	--	850	--	--	--	--	--	860
23	6.2	6.5	27	27	--	--	--	--	--	520	--	--	--	--	--	780	--	--	--	--	--	800
24	6.9	6.8	27	27	1360	102	80	555	288	500	940/800	52	44	371	468	750	920/770	52	50	309	480	800
25	6.8	7.1	27	27	--	--	--	--	--	640	--	--	--	--	--	770	--	--	--	--	--	810
26	7.2	7.5	27	27	--	--	--	--	--	490	--	--	--	--	--	760	--	--	--	--	--	780
27	7.4	7.6	27	27	1500	62	52	765	324	420	925/895	50	42	396	492	800	825/805	54	50	336	468	760
28	7.4	7.6	27	27	--	--	--	--	--	300	--	--	--	--	--	800	--	--	--	--	--	780
29	7.2	7.4	27	27	--	--	--	--	--	290	--	--	--	--	--	780	--	--	--	--	--	780
30	7.2	7.4	27	27	1420	50	40	730	--	580	905/843	60	50	545	--	780	730/710	72	62	450	--	740
31	7.2	7.5	27	27	--	--	--	--	--	540	--	--	--	--	--	780	--	--	--	--	--	800

(continued)

ANAEROBIC LAGOON DATA (continued)

Day	Anaerobic Basin pH		Anaerobic Basin Temp., °C		Anaerobic Feed						No. 1 Lagoon Effluent						No. 2 Lagoon Effluent					
	1	2	1	2	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.	COD	TSS	VSS	BOD_5	VA	Alk.
6/ 1/71	7.2	7.4	27	27	—	—	—	—	—	560	—	—	—	—	—	780	—	—	—	—	—	800
2	7.4	7.6	27	27	1325	72	52	785	360	580	895/800	80	58	568	328	800	810/760	82	66	542	504	820
3	7.4	7.6	27	27	—	—	—	—	—	580	—	—	—	—	—	800	—	—	—	—	—	820
4	7.3	7.5	27	27	—	—	—	—	—	460	—	—	—	—	—	790	—	—	—	—	—	800
5	7.2	7.4	27	27	1740	84	52	1090	552	410	930/740	80	60	524	576	880	805/705	92	68	475	492	880
6	7.2	7.4	27	27	—	—	—	—	—	520	—	—	—	—	—	910	—	—	—	—	—	920
7	7.2	7.4	27	27	—	—	—	—	—	540	—	—	—	—	—	920	—	—	—	—	—	920
8	7.2	7.4	28	28	1570	88	64	880	504	550	830/825	68	42	533	552	910	799/765	68	48	446	480	910
9	7.2	7.3	29	29	—	—	—	—	—	460	—	—	—	—	—	880	—	—	—	—	—	900
10	7.0	7.3	29	29	—	—	—	—	—	400	—	—	—	—	—	800	—	—	—	—	—	890
11	7.2	7.3	29	30	1730	84	56	1170	552	560	1100/1070	58	36	733	600	820	1020/820	98	78	663	552	900
12	7.2	7.3	30	30	—	—	—	—	—	500	—	—	—	—	—	880	—	—	—	—	—	920
13	7.1	7.3	30	30	—	—	—	—	—	510	—	—	—	—	—	860	—	—	—	—	—	920
14	7.1	7.3	30	30	1550	80	72	880	504	560	1065/1020	92	72	490	696	860	965/835	100	88	432	600	910
15	7.1	7.3	30	30	—	—	—	—	—	580	—	—	—	—	—	920	—	—	—	—	—	980
16	7.2	7.2	30	30	—	—	—	—	—	460	—	—	—	—	—	880	—	—	—	—	—	960
17	7.2	7.3	30	30	2690	116	72	1790	904	Nil	1210/1100	92	72	698	744	880	990/960	92	72	494	660	1000
18	7.0	7.2	30	30	—	—	—	—	—	800	—	—	—	—	—	880	—	—	—	—	—	900
19	7.0	7.2	29	29	—	—	—	—	—	780	—	—	—	—	—	900	—	—	—	—	—	920
20	7.0	7.3	30	30	2720	108	60	1680	840	880	1160/1120	100	64	670	744	900	1040/990	104	72	510	672	930
21	7.1	7.3	30	30	—	—	—	—	—	900	—	—	—	—	—	910	—	—	—	—	—	930
22	7.0	7.3	28	28	—	—	—	—	—	910	—	—	—	—	—	900	—	—	—	—	—	940
23	7.3	7.4	28	26	1920	116	76	1020	816	900	1110/1200	105	68	620	708	910	1060/1190	100	72	500	660	920
24	7.2	7.4	29	29	—	—	—	—	—	610	—	—	—	—	—	1060	—	—	—	—	—	1100
25	7.1	7.4	29	29	—	—	—	—	—	580	—	—	—	—	—	1080	—	—	—	—	—	1160
26	7.1	7.4	30	30	2280	100	64	1170	864	600	1390/1130	108	80	520	744	1060	1140/935	132	96	430	690	1200
27	7.1	7.4	30	30	—	—	—	—	—	600	—	—	—	—	—	1100	—	—	—	—	—	1200
28	7.2	7.2	29	29	—	—	—	—	—	660	—	—	—	—	—	1060	—	—	—	—	—	1100
29	7.2	7.2	29	29	1540	132	92	840	504	560	1160/1040	100	68	506	696	1100	1070/625	100	68	402	660	1100
30	7.1	7.2	30	30	—	—	—	—	—	500	—	—	—	—	—	1120	—	—	—	—	—	1100

TABLE 44
AERATED STABILIZATION DATA

	Basin Conditions			Feed (b)				Effluent (b)			
Day	pH	Temp., °C	D.O. (b)	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
10/ 1/70	7.8	23	7.6	--	--	--	--	--	--	--	69
2	7.0	23	2.6	520/323 (a)	150	130	122	290/205	71	63	63
3	7.0	24	1.0	--	--	--	--	--	--	--	23
4	7.7	25	3.6	--	--	--	--	/190			26
5	7.8	25	1.2	--	--	--	184	215/140	45	35	18
6	7.7	25	1.4	--	--	--	--	230/205	63	42	16
7	7.6	26	0.8	--	--	--	--	265/190	57	46	42
8	7.4	26	2.6	535/325	136	94	157	340/275	92	74	57
9	7.7	25	7.2	--	--	--	--	295/190	68	54	36
10	8.0	18	8.0	--	--	--	--	280/175	48	41	28
11	7.9	20	4.8	440/305	72	48	140	240/210	55	48	30
12	7.4	22	2.8	--	--	--	--	280/225	76	62	27
13	7.6	24	6.6	--	--	--	--	240/195	40	31	26
14	7.7	23	6.8	475/315	77	63	102	168/117	22	20	23
15	7.8	23	6.0	--	--	--	--	168/145	24	14	26
16	7.4	22	1.8	--	--	--	--	255/215	35	23	51
17	7.6	20	4.0	425/250	66	52	110	265/215	35	25	45
18	7.8	21	4.8	--	--	--	--	330/190	39	28	45
19	7.5	18	7.1	--	--	--	--	200/145	26	16	48
20	7.5	18	3.6	370/290	74	57	100	195/150	22	12	36
21	7.8	20	4.2	--	--	--	--	195/150	49	34	54
22	7.7	22	1.8	--	--	--	--	195/145	56	42	67
23	7.6	23	2.1	660/560	68	52	315	220/185	52	38	67
24	7.6	24	6.0	--	--	--	--	--	--	--	67
25	7.6	24	--	--	--	--	--	290/145	125	109	69
26	7.6	25	7.8	660/370	176	130	129	255/165	82	56	58
27	7.6	25	7.8	--	--	--	--	205/140	--	--	22
28	7.8	24	--	--	--	--	--	345/180	--	--	37
29	7.5	20	7.6	735/435	88	61	144	295/155	--	--	41
30	7.5	19	1.5	--	--	--	--	--	--	--	45
31	7.7	18	4.0	--	--	--	--	--	--	--	50

(continued)

(a) Total COD/filtered COD
(b) All units are as in Table 7

AERATED STABILIZATION DATA (continued)

	Basin Conditions			Feed				Effluent			
Day	pH	Temp., °C	D.O.(b)	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
11/ 1/70	7.8	20	1.8	--	--	--	--	--	--	--	55
2	7.8	19	1.2	440/315	110	66	130	438/210	--	--	62
3	7.6	19	0.8	--	--	--	--	445/300	--	--	71
4	7.7	18	1.8	--	--	--	--	420/310	--	--	92
5	7.7	15	0.5	475/345	106	68	145	390/205	--	--	80
6	7.6	14	1.4	--	--	--	--	335/195	156	118	64
7	7.2	15	0.8	--	--	--	--	410/295	146	102	59
8	7.6	20	0.5	330/-	70	46	92	390/310	188	100	62
9	7.3	21	1.8	--	--	--	--	395/320	240	124	70
10	7.6	18	2.0	464/350	104	72	125	360/235	126	32	66
11	7.6	20	1.0	--	--	--	--	350/250	156	122	61
12	7.6	19	0.3	--	--	--	--	295/225	142	100	107
13	7.3	17	0.7	885/600	82	54	186	345/315	140	60	71
14	7.7	16	1.6	--	--	--	--	670/440	106	76	118
15	7.7	14	0.6	--	--	--	--	745/490	94	66	144
16	7.7	13	0.8	505/415	72	42	114	555/390	96	68	132
17	7.8	14	0.8	--	--	--	--	495/365	118	80	140
18	7.8	16	0.4	--	--	--	--	360/117	118	86	132
19	7.6	18	0.8	445/370	71	61	113	410/270	116	90	96
20	7.3	18	0.8	--	--	--	--	560/	--	--	212
21	7.4	18	0.4	--	--	--	--	530/380	--	--	50
22	7.6	18	1.2	375/295	78	38	135	430/395	130	84	40
23	7.5	17	3.8	--	--	--	--	415/295	132	86	56
24	7.6	14	0.8	--	--	--	--	525/390	106	76	90
25	7.6	14	6.4	415/305	84	68	151	595/375	98	74	76
26	7.4	16	7.6	--	--	--	--	386/288	94	82	66
27	7.3	18	6.8	--	--	--	--	340/330	102	80	81
28	7.4	20	7.4	695/-	54	22	230	330/292	47	34	60
29	7.6	20	7.6	--	--	--	--	300/260	88	62	66
30	7.6	20	8.0	--	--	--	--	--	--	--	56

(b) All units mg/l.

(continued)

AERATED STABILIZATION DATA (continued)

	Basin Conditions			Feed				Effluent			
Day	pH	Temp., °C	D.O.(b)	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
12/ 1/70	7.8	21	8.2	735/675	64	40	202	340/200	180	80	76
2	7.5	22	2.6	--	--	--	--	360/200	152	100	81
3	7.6	22	4.8	--	--	--	--	348/215	161	108	64
4	7.5	23	1.0	785/695	66	30	246	400/270	184	136	127
5	7.4	23	6.2	--	--	--	--	365/245	120	72	90
6	7.4	20	4.6	--	--	--	--	370/187	128	80	78
7	7.8	18	3.8	675/630	64	20	201	335/250	132	84	72
8	7.8	18	5.6	--	--	--	--	455/240	173	107	87
9	7.9	20	7.0	--	--	--	--	295/215	176	128	83
10	7.8	21	6.2	695/610	84	44	288	375/215	208	144	78
11	7.7	20	4.2	--	--	--	--	350/215	156	100	37
12	7.8	17	6.5	--	--	--	--	380/215	128	92	27
13	7.9	17	4.6	645/545	104	36	198	420/310	152	100	42
14	8.0	17	4.0	--	--	--	--	365/295	164	108	53
15	8.0	17	3.8	--	--	--	--	300/245	144	100	93
16	7.6	18	3.6	630/610	104	56	272	390/310	168	116	97
17	7.5	18	3.8	--	--	--	--	445/310	180	128	123
18	7.7	16	4.0	825	--	--	150	420/255	208	156	54
19	7.8	19	4.4	--	--	--	--	440/310	184	116	56
20	8.0	19	4.0	--	--	--	--	420/315	176	112	50
21	7.5	20	5.2	825	--	--	210	400/270	192	140	55
22	8.2	21	6.4	820	--	--	225	485/300	256	180	50
23	8.0	21	4.6	815	--	--	174	450/280	205	150	53
24	7.7	18	4.0	845	--	--	204	500/335	260	186	63
25	7.8	19	3.2	740	--	--	200	430/350	227	160	59
26	7.8	17	4.8	725	--	--	186	455/350	220	165	64
27	7.7	19	3.0	800	--	--	222	470/390	220+	160	65
28	7.7	19	5.6	720	--	--	162	410/275	232	170	63
29	7.7	20	4.6	680	--	--	180	430/310	240	165	59
30	7.9	21	4.2	710	--	--	210	420/305	252	185	72
31	7.9	20	4.0	690	--	--	--	420/320	222	162	106

(b) All units mg/l.

(continued)

AERATED STABILIZATION DATA (continued)

	Basin Conditions			Feed				Effluent			
Day	pH	Temp., °C	D.O. (a)	COD	TSS	VSS	BOD_5	COD	TSS	VSS	BOD_5
1/ 1/71	8.0	18	2.6	--	--	--	--	440/300	180	112	118
2	7.9	19	6.0	--	--	--	--	480/290	228	140	122
3	8.0	19	5.2	395/345	68	40	126	445/255	275	175	110
4	8.3	15	5.6	--	--	--	--	495/315	380	225	128
5	8.6	8	8.0	--	--	--	--	540/305	314	200	138
6	8.1	6	7.0	415/405	48	26	154	450/355	212	142	132
7	8.6	5	3.8	--	--	--	--	490/380	156	98	135
8	8.3	5	4.0	--	--	--	--	540/405	104	78	114/70 (b)
9	8.6	9	4.6	605/530	64	36	168	590/490	114	82	132/82
10	8.1	14	4.4	--	--	--	--	685/615	100	70	178/144
11	8.3	15	5.6	--	--	--	--	665/605	92	76	199/64
12	7.9	18	8.0	715/665	70	34	180	595/440	124	96	187/74
13	7.6	19	4.6	--	--	--	--	480/280	240	144	175/54
14	7.8	20	5.2	--	--	--	--	480/270	240	172	105
15	7.6	20	3.2	595/535	70	28	186	445/265	208	136	92
16	7.5	17	4.8	--	--	--	--	475/235	216	160	72
17	7.6	16	5.2	--	--	--	--	440/260	236	176	108
18	7.7	17	4.8	570/560	58	36	162	435/235	248	188	102
19	7.8	10	3.6	--	--	--	--	455/225	252	196	104
20	8.1	12	4.8	--	--	--	--	500/290	292	208	112
21	7.8	14	5.2	645/605	56	42	131	475/265	215	125	128
22	8.0	16	4.2	--	--	--	--	445/290	225	190	132
23	8.1	17	3.8	--	--	--	--	400/190	204	164	103
24	7.5	18	5.0	630/545	40	26	206	350/210	188	147	99
25	7.9	19	4.8	--	--	--	--	360/180	184	128	76
26	7.7	20	4.2	--	--	--	--	425/215	235	185	102
27	7.6	17	3.8	635/570	54	38	222	415/195	235	190	135
28	7.7	18	2.0	--	--	--	--	380/165	195	165	54
29	7.6	19	2.8	--	--	--	--	375/170	185	150	54
30	7.3	20	3.6	625/545	42	38	274	350/190	220	180	58
31	7.6	20	3.8	--	--	--	--	410/200	230	190	37

(a) All units mg/l.
(b) Total/filtered BOD.

(continued)

AERATED STABILIZATION DATA (continued)

Basin Conditions				Feed				Effluent			
Day	pH	Temp., °C	D.O.(a)	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
2/ 1/71	7.2	20	2.8	--	--	--	--	380/175	225	185	36
2	8.1	15	4.6	615/590	42	32	219	410/210	220	195	47
3	8.1	18	3.6	--	--	--	--	410/220	224	188	77
4	8.4	17	2.2	--	--	--	--	385/165	230	198	68
5	7.8	16	3.8	680/635	48	34	259	390/210	204	182	87
6	7.7	16	6.5	--	--	--	--	360/165	144	116	54/23 (b)
7	7.7	16	6.8	--	--	--	--	355/160	192	152	42/23
8	7.8	13	5.6	595/555	78	64	202	320/145	188	156	57/22
9	7.7	12	7.7	--	--	--	--	345/155	184	144	60/25
10	7.8	10	9.2	--	--	--	--	360/125	196	160	69/36
11	7.6	11	8.5	630/605	40	26	262	410/240	216	164	83/27
12	7.7	12	9.0	--	--	--	--	405/200	212	172	72/32
13	7.8	13	8.0	--	--	--	--	370/155	225	180	44/23
14	7.8	13	8.1	685/645	62	48	140	415/190	240	190	44/23
15	7.4	16	8.0	--	--	--	--	405/245	180	155	42/26
16	7.0	19	2.4	--	--	--	--	290/160	155	110	37/23
17	7.0	19	2.4	680/660	62	40	120	260/180	115	60	31/26
18	7.1	20	4.6	--	--	--	--	370/185	190	140	56/28
19	7.2	21	3.7	--	--	--	--	320/185	182	132	69/45
20	7.3	22	4.7	645/620	46	30	168	385/185	198	142	--
21	7.6	18	3.6	--	--	--	--	210/	202	148	40/24
22	7.6	13	7.8	--	--	--	--	306/	196	148	33/19
23	7.4	13	6.8	690/	50	38	219	290/	168	156	35/19
24	7.4	14	5.0	--	--	--	--	--	--	--	40/15
25	7.1	17	2.8	--	--	--	--	385	184	144	--
26	7.1	19	2.5	715/	60	38	198	350	196	144	36/18
27	7.1	17	3.6	--	--	--	--	336	176	148	35/19
28	7.1	17	4.0	--	--	--	--	370/250	152	140	--

(a) All units mg/l.
(b) Total/filtered BOD.

(continued)

AERATED STABILIZATION DATA (continued)

	Basin Conditions			Feed				Effluent			
Day	pH	Temp., °C	D.O.(a)	COD	TSS	VSS	BOD5	COD	TSS	VSS	BOD5
3/ 1/71	7.2	19	7.2	660/585	68	36	188	385/240	176	144	35/18 (b)
2	7.0	21	3.9	--	--	--	--	285/255	184	164	34/21
3	7.2	14	3.5	--	--	--	--	390/255	192	156	34/20
4	7.2	12	5.1	680/650	68	56	208	235/240	192	168	72/55
5	7.2	16	6.0	--	--	--	--	420/235	220	176	61/27
6	7.1	15	4.0	--	--	--	--	425/165	172	148	54/23
7	7.4	14	5.2	635/555	50	38	273	475/375	148	124	97/27
8	7.5	17	6.8	--	--	--	--	415/350	100	84	104/67
9	7.2	15	6.4	--	--	--	--	395/245	56	48	90/45
10	7.3	18	1.2	660/605	36	30	312	385/360	60	48	100/56
11	7.5	18	5.6	--	--	--	--	365/285	96	72	72/58
12	7.2	20	4.0	--	--	--	--	345/225	112	76	70/21
13	7.4	21	3.6	605/575	72	50	231	335/218	88	64	90/59
14	7.3	22	3.4	--	--	--	--	340/180	142	126	93/57
15	7.4	20	2.0	--	--	--	--	330/220	60	30	98/62
16	7.5	20	2.4	715/625	70	50	264	330/250	114	90	108/71
17	7.4	21	1.2	--	--	--	--	330/260	92	82	79/21
18	7.2	20	3.6	--	--	--	--	340/255	126	120	93/18
19	7.4	15	2.2	560/540	44	38	303	320/200	124	110	75/15
20	7.2	15	7.0	--	--	--	--	320/180	164	136	60/26
21	7.3	17	3.8	--	--	--	--	385/205	158	138	80/18
22	7.5	19	1.5	653/585	44	36	182	415/200	114	108	72/21
23	7.5	21	3.3	--	--	--	--	340/195	148	144	54/16
24	7.6	20	1.0	--	--	--	--	480/450	200	192	115/32
25	7.7	21	4.0	770/705	38	28	246	415/195	192	176	76/18
26	7.2	19	2.4	--	--	--	--	450/230	236	224	82/36
27	7.8	17	9.2	--	--	--	--	525/275	164	160	114/47
28	7.3	19	2.0	675/600	40	38	262	400/330	70	68	105/50
29	7.4	21	2.5	--	--	--	--	455/560	62	50	114/58
30	7.6	18	2.2	--	--	--	--	425/300	104	84	100/49
31	7.5	20	1.8	820/735	58	42	303	480/360	120	96	119/32

(a) All units mg/l.
(b) Total/filtered BOD.

(continued)

AERATED STABILIZATION DATA (continued)

				Feed				Effluent			
Day	pH	Temp., °C	D.O.	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	BOD$_5$
4/ 1/71	7.6	21	2.4	--	--	--	--	470/360	126	116	68/26 (b)
2	7.9	18	7.4	--	--	--	--	605/200	270	215	71/24
3	7.8	17	5.2	850/715	76	60	366	505/275	215	175	71/27
4	7.8	18	6.5	--	--	--	--	500/280	196	168	57/22
5	7.9	17	6.2	--	--	--	--	535/340	184	156	47/25
6	8.1	14	7.0	885/780	58	46	372	465/265	200	168	60/13
7	7.7	15	2.6	--	--	--	--	440/295	140	108	58/24
8	7.9	16	5.8	--	--	--	--	500/230	244	200	85/30
9	7.7	18	2.0	730/890	52	40	319	495/250	192	180	104/33
10	7.6	20	1.8	--	--	--	--	495/270	224	180	88/30
11	7.8	20	4.0	--	--	--	--	495/260	224	192	98/28
12	7.8	20	5.4	770/765	76	58	284	500/260	226	196	101/28
13	7.9	24	4.2	--	--	--	--	505/270	224	200	105/28
14	8.0	21	6.3	--	--	--	--	480/230	224	184	77/29
15	7.7	22	6.0	950/	60	40	292	530/	208	164	78/25
16	7.7	21	4.8	--	--	--	--	485/230	232	200	73/28
17	7.8	21	5.6	--	--	--	--	--	--	--	--
18	7.8	21	4.2	895/	72	60	303	465/220	232	196	89/19
19	7.7	23	2.4	--	--	--	--	465/215	232	192	82/28
20	7.8	23	2.0	--	--	--	--	475/205	256	220	85/17
21	7.5	22	4.5	705/565	60	52	162	500/260	256	228	100/35
22	7.5	22	4.2	--	--	--	--	510/245	280	236	95/23
23	7.6	22	5.0	--	--	--	--	495/225	260	232	64/22
24	7.9	21	2.4	960/780	58	46	306	550/250	296	264	78/21
25	7.9	21	2.3	--	--	--	--	525/260	268	240	66/22
26	7.8	22	2.0	--	--	--	--	565/340	292	272	63/25
27	7.8	24	1.0	1065/955	60	38	432	690/385	292	208	109/33
28	7.9	24	2.3	--	--	--	--	570/308	328	284	122/21
29	7.7	24	3.2	--	--	--	--	635/300	332	292	122/30
30	8.2	24	4.0	1140/1030	62	52	--	600/295	260	228	--

(b) Total/filtered BOD.

(continued)

AERATED STABILIZATION DATA (continued)

Day	pH	Temp., °C	D.O.	Feed COD	Feed TSS	Feed VSS	Feed BOD_5	Effluent COD	Effluent TSS	Effluent VSS	Effluent BOD_5
5/ 1/71	8.1	21	4.9	--	--	--	--	715/320	405	320	180/33 (b)
2	7.2	21	1.8	--	--	--	--	495/255	365	320	165/17
3	7.9	22	2.8	975/890	70	58	532	565/245	316	276	172/28
4	7.9	23	3.5	--	--	--	--	560/260	300	272	174/31
5	8.0	23	5.0	--	--	--	--	570/245	316	280	178/42
6	7.8	24	1.3	1223/1170	78	54	561	520/245	336	292	170/36
7	8.2	25	4.7	--	--	--	--	540/250	312	292	168/34
8	8.2	25	4.9	--	--	--	--	585/250	288	252	Broke
9	8.3	24	5.3	1255/1075	68	52	Broke	560/260	292	252	--
10	8.6	24	7.0	--	--	--	--	530/350	268	236	--
11	8.1	23	4.1	--	--	--	--	565/265	316	268	--
12	7.7	21	3.0	1070/970	84	74	Broke	565/275	312	276	--
13	7.8	19	4.1	--	--	--	--	545/175	--	--	124/42
14	7.9	18	7.8	--	--	--	--	440/150	292	264	105/19
15	7.8	20	0.2	895/850	90	78	429	575/208	328	276	116/43
16	7.8	22	4.9	--	--	--	--	--	340	292	105/34
17	7.9	22	3.9	-	--	--	--	540/185	352	316	89/31
18	8.1	23	3.3	830/675	74	64	360	--	316	280	102/39
19	7.7	24	4.3	--	--	--	--	415/145	--	--	102/47
20	8.0	24	4.6	--	--	--	--	405/105	292	244	87/43
21	8.3	24	5.3	945/910	66	58	370	520/270	244	220	86/37
22	7.7	24	5.9	--	--	--	--	465/230	240	200	71/40
23	8.0	24	7.7	--	--	--	--	415/230	212	184	51/25
24	8.6	24	7.6	940/800	52	44	371	430/240	228	180	48/23
25	8.5	25	6.2	--	--	--	--	445/240	212	208	63/19
26	8.1	25	4.6	--	--	--	--	430/225	224	184	75/26
27	7.6	26	3.7	925/895	50	42	396	420/240	204	188	82/30
28	7.4	26	4.0	--	--	--	--	445/215	230	176	75/43
29	7.7	25	3.6	--	--	--	--	375/155	196	164	82/60
30	7.5	25	2.6	905/843	60	50	545	420/175	208	184	104/36
31	7.6	25	4.3	--	--	--	--	440/205	209	184	77/31

(b) Total/filtered BOD.

(continued)

AERATED STABILIZATION DATA (continued)

Day	pH	Temp., °C	D.O.	Feed				Effluent			
				COD	TSS	VSS	BOD_5	COD	TSS	VSS	BOD_5
6/ 1/71	7.8	25	3.8	--	--	--	--	450/355	216	188	85/57 (b)
2	7.4	25	4.0	895/800	80	58	568	425/360	232	196	88/49
3	7.3	24	1.2	--	--	--	--	445/180	248	202	--
4	7.3	24	5.8	--	--	--	--	380/235	272	180	75/35
5	7.4	24	3.0	930/740	80	60	524	420/190	240	200	104/31
6	7.3	24	2.8	--	--	--	--	470/210	244	200	116/35
7	7.0	25	2.4	--	--	--	--	425/200	220	188	98/34
8	7.1	25	3.0	830/825	68	42	533	350/185	264	272	78/32
9	7.2	26	5.5	--	--	--	--	320/315	246	208	66/27
10	7.1	27	2.8	--	--	--	--	485/250	270	228	113/37
11	7.1	27	3.2	1100/1070	58	36	733	553/310	296	262	114/58
12	6.9	27	2.6	--	--	--	--	570/295	252	240	100/55
13	6.8	27	3.8	--	--	--	--	515/300	228	204	112/49
14	6.8	27	2.3	1068/1020	92	72	490	565/295	292	264	117/36
15	7.0	27	1.3	--	--	--	--	430/326	276	248	124/53
16	7.1	27	5.5	--	--	--	--	505/370	264	224	104/36
17	6.9	26	5.8	1210/1100	92	72	698	555/245	240	204	127/40
18	7.0	27	2.0	--	--	--	--	510/280	308	220	110/32
19	7.1	26	5.6	--	--	--	--	430/275	276	196	120/78
20	7.1	26	4.8	1180/1120	100	64	670	415/240	220	160	124/30
21	7.0	26	4.4	--	--	--	--	510/310	180	140	121/42
22	6.9	26	4.8	--	--	--	--	575/220	300	256	122/59
23	7.0	26	3.6	1110/1240	104	68	620	560/395	244	292	117/36
24	7.2	27	4.2	--	--	--	--	590/300	332	286	120/40
25	7.3	27	4.2	--	--	--	--	555/315	284	224	66/31
26	7.1	[illegible]	5.8	1390/1130	108	80	520	540/370	296	228	67/22
27	7.1	27	6.0	--	--	--	--	515/380	268	196	50/17
28	7.2	27	6.0	--	--	--	--	573/385	272	208	64/22
29	7.2	26	6.5	1160/1040	100	68	506	510/270	266	220	52/21
30	7.2	27	3.8	--	--	--	--	500/255	270	228	--

(b) Total/filtered BOD.

TABLE 45
FACULTATIVE LAGOON DATA

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD (a)	TSS	VSS	BOD_5	COD	TSS	VSS	COD	TSS	VSS	BOD_5
10/ 7/70	265/190	57	46	42	--	--	--	280/190	56	44	--
8	340/275	92	74	57	--	--	--	--	--	--	--
9	295/190	68	54	36	--	--	--	--	--	--	--
10	280/175	48	41	28	--	--	--	--	--	--	--
11	240/210	55	48	30	--	--	--	--	--	--	--
12	280/225	76	62	27	--	--	--	--	--	--	--
13	240/193	40	31	26	--	--	--	--	--	--	--
14	168/117	22	20	23	--	--	--	--	--	--	--
15	168/145	24	14	26	220/153	66	41	168/143	65	38	--
16	255/215	35	23	51	--	--	--	--	--	--	--
17	265/215	35	25	45	--	--	--	--	--	--	--
18	330/190	34	28	45	--	--	--	--	--	--	--
19	200/140	26	16	48	--	--	--	--	--	--	--
20	105/150	22	12	36	--	--	--	--	--	--	--
21	195/150	49	34	54	--	--	--	--	--	--	--
22	195/145	56	42	67	--	--	--	--	--	--	--
23	320/185	52	38	67	--	--	--	--	--	--	--
24	--	--	--	67	--	--	--	--	--	--	--
25	290/145	125	109	69	--	--	--	--	--	--	--
26	255/165	82	56	58	--	--	--	--	--	--	--
27	205/140	--	--	--	--	--	--	--	--	--	--
28	345/180	--	--	--	--	--	--	--	--	--	--
29	295/155	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--

(continued)

(a) Total COD/filtered COD
(b) All units are as in Table 7

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD_5	COD	TSS	VSS	COD	TSS	VSS	BOD_5
11/ 1/70	--	--	--	55	--	--	--	--	--	--	--
2	430/210	--	--	62	--	--	--	--	--	--	28
3	445/300	--	--	71	--	--	--	--	--	--	--
4	420/310	--	--	92	--	--	--	--	--	--	--
5	390/205	--	--	80	--	--	--	--	--	--	15
6	335/195	156	118	64	--	--	--	--	--	--	--
7	410/295	148	102	59	--	--	--	--	--	--	--
8	390/310	188	100	62	280/210	70	46	200/160	60	36	40
9	395/320	240	124	70	--	--	--	--	--	--	--
10	360/235	126	32	66	--	--	--	--	--	--	--
11	350/250	156	122	61	330/270	--	--	270/240	--	--	30
12	295/225	142	100	107	--	--	--	--	--	--	--
13	345/315	140	60	71	--	--	--	--	--	--	--
14	670/440	106	76	118	--	--	--	--	--	--	--
15	745/490	94	66	144	330/315	106	76	360/260	68	38	36
16	555/390	96	68	132	--	--	--	--	--	--	--
17	495/365	118	80	140	--	--	--	--	--	--	--
18	360/117	118	86	132	310/160	66	51	335/145	53	38	64
19	410/270	116	90	96	--	--	--	--	--	--	--
20	560/--	--	--	212	--	--	--	--	--	--	--
21	530/380	--	--	50/45 (a)	--	--	--	--	--	--	--
22	430/395	130	84	40/56	405/360	74	68	--	--	--	46
23	415/295	132	86	56/49	--	--	--	--	--	--	--
24	525/390	106	76	90/76	430/320	98	62	394/355	78	54	62
25	595/375	98	74	76/94	--	--	--	--	--	--	--
26	386/288	94	82	66/71	--	--	--	--	--	--	--
27	340/330	102	80	81/65	410/296	80	64	[illegible]/278	74	58	93
28	330/296	47	34	60/69	--	--	--	--	--	--	--
29	302/260	88	62	66/66	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--	74

(a) Total BOD/Filtered BOD

(continued)

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	COD	TSS	VSS	BOD$_5$
12/ 1/70	340/220	108	80	76/--	370/255	86	74	--	--	--	--
2	360/200	152	100	81/--	--	--	--	327/225	84	64	68
3	345/215	161	108	64/49	353/240	112	86	--	--	--	--
4	400/270	184	136	127/74	--	--	--	--	--	--	--
5	365/245	120	72	90/48	--	--	--	320/220	84	44	72
6	370/187	128	80	78/37	335/220	52	46	--	--	--	--
7	355/250	132	84	72/40	--	--	--	--	--	--	--
8	455/240	173	107	87/41	--	--	--	295/195	104	68	78
9	295/215	176	128	83/63	325/235	114	86	--	--	--	--
10	375/215	208	144	78/40	--	--	--	--	--	--	--
11	350/215	156	100	37/47	--	--	--	300/190	108	56	45
12	380/215	128	92	27/38	295/185	104	56	--	--	--	--
13	420/310	152	100	42/62	--	--	--	--	--	--	--
14	365/295	164	108	53/61	--	--	--	290/240	88	40	66
15	300/245	144	100	93	310/240	108	60	--	--	--	--
16	370/310	168	116	97	--	--	--	--	--	--	--
17	445/310	180	128	123	--	--	--	290/205	108	64	32
18	422/255	208	156	54	335/280	120	84	--	--	--	--
19	440/310	184	116	56	--	--	--	--	--	--	--
20	420/315	176	112	50	--	--	--	350/235	156	104	36
21	400/270	192	140	55	380/285	128	96	--	--	--	--
22	485/300	256	180	50	--	--	--	--	--	--	--
23	450/180	205	150	53	--	--	--	330/280	80	60	38
24	500/335	260	186	63	400/275	86	70	--	--	--	--
25	430/350	227	160	59	--	--	--	--	--	--	--
26	455/350	220	165	64	--	--	--	325/300	76	56	31
27	470/390	220	160	65	395/315	104	76	--	--	--	--
28	410/275	232	170	63	--	--	--	--	--	--	--
29	430/310	240	165	59	--	--	--	365/315	94	60	62
30	470/305	252	185	72	415/370	112	80	--	--	--	--
31	420/320	222	162	--	--	108	--	--	--	--	--

(continued)

FACULTATIVE LAGOON DATA (continued)

Day	COD	TSS	VSS	BOD	COD	TSS	VSS	COD	TSS	VSS	BOD
1/ 1/71	440/300	180	112	118	--	--	--	--	--	--	--
2	480/290	228	140	122	365/215	178	126	320/255	--	--	70
3	445/255	275	175	110	--	--	--	--	--	--	--
4	495/315	380	225	128	--	--	--	--	--	--	--
5	540/305	314	200	138	415/330	194	145	380/315	172	134	76
6	450/355	212	142	132	--	--	--	--	--	--	--
7	490/380	156	98	135	--	--	--	--	--	--	--
8	540/405	104	78	114/70	385/330	132	93	395/295	98	68	56
9	590/490	114	82	132/82	--	--	--	--	--	--	--
10	685/615	100	70	178/144	--	--	--	--	--	--	--
11	665/605	92	76	199/64	510/445	66	72	435/395	95	74	68
12	595/440	124	96	187/74	--	--	--	--	--	--	--
13	480/280	240	144	175/54	--	--	--	--	--	--	--
14	480/270	240	172	105	440/360	104	44	455/340	114	64	67
15	445/265	208	136	92	--	--	--	--	--	--	--
16	475/235	216	160	72	--	--	--	--	--	--	--
17	440/260	236	176	108	305/280	86	58	305/265	70	50	37
18	435/235	248	188	102	--	--	--	--	--	--	--
19	455/225	252	196	104	--	--	--	--	--	--	--
20	500/290	292	208	112	340/285	124	84	335/295	94	60	56
21	475/265	215	125	128	--	--	--	--	--	--	--
22	445/290	225	190	132	--	--	--	--	--	--	--
23	400/190	204	164	103	320/305	106	80	295/225	84	60	55
24	350/210	188	148	99	--	--	--	--	--	--	--
25	360/180	184	128	76	--	--	--	--	--	--	--
26	425/215	235	185	106	290/260	116	72	285/235	96	64	49
27	415/195	235	190	135	--	--	--	--	--	--	--
28	380/165	195	165	54	--	--	--	--	--	--	--
29	375/170	185	150	54	230/185	88	64	290/195	72	48	32
30	350/190	220	180	58	--	--	--	--	--	--	--
31	410/200	230	190	37	--	--	--	--	--	--	--

(continued)

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD	COD	TSS	VSS	COD	TSS	VSS	BOD
2/ 1/71	380/175	225	185	36	--	--	--	--	--	--	--
2	410/210	220	195	47	246/165	88	76	200/165	60	48	31
3	410/220	224	188	77	--	--	--	--	--	--	--
4	385/165	230	198	68	290/200	102	84	250/170	88	66	42
5	390/210	204	182	87	--	--	--	--	--	--	--
6	360/165	144	116	54/23	--	--	--	--	--	--	--
7	335/160	192	152	42/23	265/170	96	78	255/185	78	58	32
8	320/145	188	156	57/22	--	--	--	--	--	--	--
9	345/155	184	144	60/25	--	--	--	--	--	--	--
10	360/125	196	160	69/36	240/160	90	70	210/160	72	60	32
11	410/240	216	164	83/27	--	--	--	--	--	--	--
12	405/200	212	172	72/32	--	--	--	--	--	--	--
13	370/155	225	180	44/23	240/185	84	68	210/195	76	48	28/22 (a)
14	415/190	240	190	44/23	--	--	--	--	--	--	--
15	405/245	180	155	42/26	--	--	--	--	--	--	--
16	290/160	155	110	37/23	230/195	74	46	225/185	68	42	26/26
17	260/180	115	60	31/26	--	--	--	--	--	--	--
18	370/185	190	140	56/28	--	--	--	--	--	--	--
19	320/185	182	132	69/45	225/200	42	28	210/195	46	30	34/27
20	385/185	198	142	--	--	--	--	--	--	--	--
21	210/	202	148	40/24	--	--	--	--	--	--	--
22	340/	196	148	33/19	210/	46	31	290/	34	23	32/16
23	290/	168	156	35/19	--	--	--	--	--	--	--
24	--	--	--	40/15	--	--	--	--	--	--	--
25	288	184	144	--	--	76	52	162	42	26	--
26	350	196	144	36/18	--	--	--	--	--	--	--
27	336	176	148	35/19	--	--	--	--	--	--	--
28	370/250	152	140	--	327/177	70	64	210/170	52	44	--

(a) Total/filtered BOD_5.

(continued)

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD	COD	TSS	VSS	COD	TSS	VSS	BOD
3/ 1/71	385/240	176	144	35/18	--	--	--	--	--	--	--
2	285/255	184	164	34/21	--	--	--	--	--	--	--
3	390/255	192	156	34/20	275/245	84	72	245/205	60	30	31/15
4	285/240	192	168	72/55	--	--	--	--	--	--	--
5	425/235	200	176	61/27	--	--	--	--	--	--	--
6	425/165	172	140	54/23	315/240	90	76	260/190	68	54	26/14
7	475/375	148	124	97/27	--	--	--	--	--	--	--
8	415/350	100	84	104/67	--	--	--	--	--	--	--
9	395/245	56	48	90/45	380/280	80	68	335/225	68	60	42/32
10	365/360	60	48	100/56	--	--	--	--	--	--	--
11	365/285	96	72	78/58	--	--	--	--	--	--	--
12	345/225	112	76	70/21	340/245	42	28	310/230	36	30	67/40
13	335/210	88	64	90/59	--	--	--	--	--	--	--
14	340/180	142	126	93/57	--	--	--	--	--	--	--
15	330/220	60	30	98/62	290/180	50	34	245/210	40	22	41/--
16	330/250	114	90	108/71	--	--	--	--	--	--	--
17	330/260	92	82	79/21	--	--	--	--	--	--	--
18	340/255	126	120	93/18	385/260	46	44	243/230	34	32	42/17
19	320/200	124	110	75/15	--	--	--	--	--	--	--
20	320/180	164	136	60/26	--	--	--	--	--	--	--
21	385/205	158	138	80/18	245/215	52	44	260/215	34	28	36/34
22	415/200	114	108	72/21	--	--	--	--	--	--	--
23	340/195	148	144	54/16	--	--	--	--	--	--	--
24	480/450	200	192	115/32	300/210	88	86	265/210	48	46	36/20
25	115/195	192	176	76/18	--	--	--	--	--	--	--
26	450/230	236	224	82/36	--	--	--	--	--	--	--
27	525/275	164	160	114/47	280/200	88	86	265/185	50	48	57/20
28	400/330	70	68	105/50	--	--	--	--	--	--	--
29	455/360	62	50	114/48	--	--	--	--	--	--	--
30	420/300	104	84	100/49	345/270	62	48	280/265	44	34	65/25
31	480/360	120	96	119/32	--	--	--	--	--	--	--

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD_5	COD	TSS	VSS	COD	TSS	VSS	BOD_5
4/ 1/71	470/360	126	116	68/26	--	--	--	--	--	--	--
2	605/290	270	215	71/24	415/355	72	52	315/280	60	38	64/30
3	505/275	215	175	71/27	--	--	--	--	--	--	--
4	500/280	196	168	57/22	--	--	--	--	--	--	--
5	535/340	184	156	47/25	465/380	66	56	365/355	36	30	45/22
6	465/265	200	168	60/13	--	--	--	--	--	--	--
7	440/295	140	108	58/24	--	--	--	--	--	--	--
8	500/230	244	200	85/30	300/225	62	48	280/240	46	32	35/18
9	495/250	192	180	104/33	--	--	--	--	--	--	--
10	495/270	224	180	88/30	--	--	--	--	--	--	--
11	495/260	224	192	98/28	520/270	94	82	310/265	62	28	39/20
12	500/260	224	196	101/28	--	--	--	--	--	--	--
13	505/270	224	200	105/28	--	--	--	--	--	--	--
14	480/230	224	184	77/29	325/240	136	104	335/280	92	72	41/20
15	530/	208	164	78/25	--	--	--	--	--	--	--
16	485/230	232	200	73/28	--	--	--	--	--	--	--
17	--	--	--	--	--	128	120	375/290	88	80	40/19
18	465/220	232	196	89/19	--	--	--	--	--	--	--
19	465/215	232	192	82/28	--	--	--	--	--	--	--
20	475/205	256	220	85/17	355/210	140	128	300/215	116	92	43/21
21	500/260	256	228	100/35	--	--	--	--	--	--	--
22	510/245	280	236	95/23	--	--	--	--	--	--	--
23	495/225	260	232	64/22	395/265	122	106	330/250	88	80	27/10
24	550/250	296	264	78/21	--	--	--	--	--	--	--
25	525/260	268	240	66/22	--	--	--	--	--	--	--
26	565/340	292	272	63/25	465/350	140	128	370/355	108	96	94/19
27	690/385	292	208	109/33	--	--	--	--	--	--	--
28	570/308	328	284	122/21	--	--	--	--	--	--	--
29	635/300	332	292	122/30	480/325	176	152	420/295	136	120	65/12
30	600/295	260	228	--	--	--	--	--	--	--	--

(continued)

FACULTATIVE LAGOON DATA (continued)

	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
Day	COD	TSS	VSS	BOD_5	COD	TSS	VSS	COD	TSS	VSS	BOD_5
5/ 1/71	715/320	405	320	180/33	--	--	--	--	--	--	--
2	495/255	365	320	165/17	425/320	144	132	360/270	124	108	51/19
3	565/245	316	276	172/28	--	--	--	--	--	--	--
4	560/260	300	272	174/31	--	--	--	--	--	--	--
5	570/245	316	280	178/42	435/320	160	140	405/310	124	112	52/21
6	520/245	336	292	170/36	--	--	--	--	--	--	--
7	540/250	312	292	168/34	--	--	--	--	--	--	--
8	585/250	288	252	Broke	465/280	148	144	410/296	124	112	63/37
9	560/260	292	252	--	--	--	--	--	--	--	--
10	530/350	268	236	--	--	--	--	--	--	--	--
11	565/265	316	268	--	420/315	136	124	410/295	124	100	61/34
12	565/275	312	276	--	--	--	--	--	--	--	--
13	545/175	--	--	124/42	--	--	--	--	--	--	--
14	440/150	292	264	105/19	380/205	136	128	310/200	108	104	57/37
15	575/205	328	276	116/43	--	--	--	--	--	--	--
16	--	340	292	105/34	--	--	--	--	--	--	--
17	540/185	352	316	69/31	385/205	160	144	320/200	112	104	61/34
18	--	316	280	102/39	--	--	--	--	--	--	--
19	415/145	--	--	102/47	--	--	--	--	--	--	--
20	405/105	292	244	87/43	360/145	200	172	275/145	148	128	51/38
21	520/270	244	220	86/37	--	--	--	--	--	--	--
22	465/230	240	200	71/40	--	--	--	--	--	--	--
23	415/230	212	184	51/25	395/260	158	136	345/245	128	112	38/26
24	430/240	228	180	48/23	--	--	--	--	--	--	--
25	445/240	212	208	63/19	--	--	--	--	--	--	--
26	430/225	224	184	75/26	355/290	120	96	320/255	108	84	52/22
27	420/240	204	188	82/30	--	--	--	--	--	--	--
28	445/215	200	176	75/43	--	--	--	--	--	--	--
29	375/155	196	164	82/60	320/305	94	80	315/260	80	70	51/46
30	420/175	208	184	104/36	--	--	--	--	--	--	--
31	490/205	209	184	77/31	--	--	--	--	--	--	--

(continued)

FACULTATIVE LAGOON DATA (continued)

Day	Facultative Lagoon Feed				No. 1 Lagoon			No. 2 Lagoon Effluent			
	COD	TSS	VSS	BOD$_5$	COD	TSS	VSS	COD	TSS	VSS	BOD$_5$
6/ 1/71	450/355	216	188	85/57	245/240	82	74	290/235	86	76	65/38
2	425/360	232	196	88/49	--	--	--	--	--	--	--
3	445/180	248	202	--	--	--	--	--	--	--	--
4	380/235	272	180	75/35	300/285	72	56	330/260	100	88	50/25
5	420/190	240	200	104/31	--	--	--	--	--	--	--
6	470/210	244	200	116/35	--	--	--	--	--	--	--
7	425/200	220	188	98/34	355/220	92	72	305/240	88	72	48/28
8	380/185	264	212	78/32	--	--	--	--	--	--	--
9	320/315	246	208	66/27	--	--	--	--	--	--	--
10	485/250	270	228	113/37	330/230	102	84	295/245	76	58	57/31
11	553/310	296	262	114/58	--	--	--	--	--	--	--
12	570/275	252	240	100/55	--	--	--	--	--	--	--
13	515/300	228	204	112/49	425/300	164	132	330/270	128	112	35/15
14	565/295	292	264	117/36	--	--	--	--	--	--	--
15	430/320	276	248	124/53	--	--	--	--	--	--	--
16	505/370	264	224	104/36	370/340	100	88	380/270	56	44	61/36
17	555/245	240	204	127/40	--	--	--	--	--	--	--
18	510/280	308	220	110/32	--	--	--	--	--	--	--
19	460/275	276	196	102/28	395/350	96	64	305/295	72	56	46/21
20	415/240	220	160	104/30	--	--	--	--	--	--	--
21	510/310	180	140	121/42	--	--	--	--	--	--	--
22	575/220	300	256	122/39	400/340	104	88	290/275	116	100	42/28
23	560/395	244	292	117/36	--	--	--	--	--	--	--
24	590/300	332	286	120/40	--	--	--	--	--	--	--
25	555/315	284	224	66/31	435/350	104	92	325/285	68	44	43/23
26	540/370	296	228	67/22	--	--	--	--	--	--	--
27	615/380	268	196	50/17	--	--	--	--	--	--	--
28	570/305	272	208	64/22	420/370	112	80	355/--	76	48	34/15
29	510/270	266	220	52/21	--	--	--	--	--	--	--
30	500/255	270	228	--	--	--	--	--	--	--	--

TABLE 46

ANAEROBIC BASIN PROFILES

I. 4 a.m. 10/1/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.4	7.3	7.5	7.9	7.4	7.4	7.4	8.0
ORP, mv	-340	-360	-350	-320	-340	-370	-370	-390
Temp., °C	26	26	26	26	26	26	26	26
COD_T/COD_F, mg/l	1060/705	905/695	895/605	910/540	755/735	760/815	750/670	610/550
VA, mg/l as HAc	250	250	215	205	215	215	130	180
TOC, mg/l (a)	200	215	195	150	145	135	180	100
S=, mg/l	59	60	69	76	47	55	45	73
SO_4, mg/l	204	188	120	84	204	208	208	100

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.7	7.7	8.0	7.7	7.7	8.1
ORP, mv	-320	-330	-370	-35	-360	-380
Temp., °C	25	25	25	25	25	25
COD_T/COD_F, mg/l	595/535	585/510	585/460	630/455	625/475	555/540
VA, mg/l as HAc	215	215	170	215	205	180
TOC, mg/l	90	105	110	160	145	75
S=, mg/l	39	45	33	35	32	43
SO_4, mg/l	140	92	148	156	140	188

(a) All samples for total carbon determinations are filtered and nitrogen purged at low pH

ANAEROBIC BASIN PROFILES (continued)

I. 4 p.m. 10/1/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	8.0	7.7	7.7	8.0	8.0	7.7	7.7	8.0
ORP, mv	-320	-350	-360	-380	-320	-340	-350	-380
Temp., °C	31	30	30	30	31	30	30	30
COD_T/COD_F, mg/l	795/695	825/710	925/685	1680/595	755/575	680/610	755/505	455/430
VA, mg/l as HAc	270	265	240	210	210	215	140	190
TOC, mg/l	230	235	220	200	200	220	180	150
$S^=$, mg/l	50	54	70	84	51	53	70	84
SO_4, mg/l	256	258	166	66	254	204	166	68

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	8.0	7.8	7.8	8.0	8.0	7.9
ORP, mv	-320	-350	-390	-330	-370	-350
Temp., °C	31	31	30	31	31	30
COD_T/COD_F, mg/l	570/495	565/515	525/430	590/495	565/515	525/430
VA, mg/l as HAc	220	220	180	215	205	180
TOC, mg/l	125	140	110	140	125	130
$S^=$, mg/l	22	26	64	31	46	37
SO_4, mg/l	180	182	68	190	164	166

ANAEROBIC BASIN PROFILES (continued)

II. 4 a.m. 10/8/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.3	7.3	7.2	7.9	7.3	7.3	7.2	8.0
ORP, mv	-340	-350	-360	-400	-350	-360	-360	-370
Temp., °C	29	29	29	28	29	29	29	29
COD_T/COD_F, mg/l	735/640	730/655	720/620	2630/570	710/710	735/650	720/720	2600/830
VA, mg/l as HAc	265	250	265	145	275	265	265	170
TOC, mg/l	245	200	230	190	290	240	240	165
$S^=$, mg/l	49	51	48	102	38	50	51	112
SO_4, mg/l	270	265	265	20	290	300	290	40

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.7	7.7	7.6	7.7	7.7	7.6
ORP, mv	-350	-360	-370	-250	-240	-220
Temp., °C	27.5	27.5	27.5	27	27.5	27.5
COD_T/COD_F, mg/l	570/510	565/530	1780/470	575/570	590/575	930/720
VA, mg/l as HAc	215	190	190	190	205	190
TOC, mg/l	140	180	180	180	150	190
$S^=$, mg/l	37	38	38	34	38	42
SO_4, mg/l	210	210	215	240	195	195

ANAEROBIC BASIN PROFILES (continued)

VI. 4:30 p.m. on 2/17/71

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.0	6.8	6.7	6.8	6.9	6.9	6.9	6.9
ORP, mv	-300	-305	-300	-300	-300	-310	-310	-290
Temp., °C	24	24	24	24	24	24	24	23
COD_T/COD_F, mg/l	685/580	690/585	700/595	655/530	635/530	675/565	630/560	670/550
VA, mg/l as HAc	216	240	264	264	264	278	278	264
TOC, mg/l	205	205	210	200	195	180	180	185
S=, mg/l	15	20	23	47	19	18	16	38
SO_4, mg/l	380	375	360	290	375	380	370	300

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.0	7.0	7.0	7.1	7.1	7.1
ORP, mv	-280	-280	-300	-290	-300	-310
Temp., °C	23	23	23	23	23	23
COD_T/COD_F, mg/l	635/540	620/505	615/440	615/380	615/400	640/420
VA, mg/l as HAc	192	204	240	228	240	264
TOC, mg/l	170	165	160	160	165	165
S=, mg/l	5	5	29	5	5	21
SO_4, mg/l	380	410	305	380	385	290

ANAEROBIC BASIN PROFILES (continued)

III. 4 a.m. on 10/29/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.5
ORP, mv	-340	-340	-340	-340	-340	-350	-350	-340
Temp., °C	24	24	24	24	24	25	24	24
COD_T/COD_F, mg/l	800/520	820/590	800/605	790/585	785/665	775/605	780/605	780/615
VA, mg/l as HAc	228	228	240	240	228	216	228	228
TOC, mg/l	175	190	190	175	195	185	195	195
$S^=$, mg/l	68	70	69	70	68	68	70	75
SO_4, mg/l	80	82	80	80	65	70	72	70

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.4	7.4	7.4	7.4	7.4	7.4
ORP, mv	-320	-340	-340	-340	-340	-340
Temp., °C	24	24	24	23	24	24
COD_T/COD_F, mg/l	615/520	615/520	620/500	695/525	635/570	680/495
VA, mg/l as HAc	120	132	144	120	180	180
TOC, mg/l	210	210	195	180	195	180
$S^=$, mg/l	46	43	43	40	42	39
SO_4, mg/l	105	100	103	84	75	78

ANAEROBIC BASIN PROFILES (continued)

II. 4 p.m. on 10/8/70

Deep Lagoon

Parameter	Inlet Surface	Inlet 3 ft	Inlet 6 ft	Inlet Sludge	Outlet Surface	Outlet 3 ft	Outlet 6 ft	Outlet Sludge
pH	6.9	6.9	6.9	7.7	6.9	6.9	6.9	7.7
ORP, mv	-330	-320	-350	-370	-350	-300	-350	-365
Temp., °C	27.5	28	28	28	28	28	28	27.5
COD_T/COD_F, mg/l	710/580	740/560	740/615	1805/440	680/595	725/585	715/605	1585/475
VA, mg/l as HAc	260	250	260	145	270	260	260	180
TOC, mg/l	210	215	210	180	150	155	155	105
$S^=$, mg/l	46	48	44	109	33	31	34	103
SO_4, mg/l	245	255	260	80	290	285	285	20

Shallow Lagoon

Parameter	Inlet Surface	Inlet 3 ft	Inlet Sludge	Outlet Surface	Outlet 3 ft	Outlet Sludge
pH	7.3	7.3	7.4	7.3	7.3	7.3
ORP, mv	-340	-350	-365	-320	-330	-340
Temp., °C	27.5	28	28	27.5	28	28
COD_T/COD_F, mg/l	650/475	615/495	935/530	535/405	530/425	660/450
VA, mg/l as HAc	210	195	195	200	205	195
TOC, mg/l	185	180	140	130	130	150
$S^=$, mg/l	30	26	37	33	32	40
SO_4, mg/l	205	210	180	195	200	165

ANAEROBIC BASIN PROFILES (continued)

III. 3 p.m. on 10/29/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.4	7.4	7.2	7.2	7.4	7.3	7.3	7.3
ORP, mv	-410	-420	-420	-420	-400	-420	-410	-420
Temp., °C	25	25	25	24	25	25	25	24
COD_T/COD_F, mg/l	745/510	770/585	775/545	750/510	740/525	755/530	770/545	715/510
VA, mg/l as HAc	150	165	190	220	160	170	185	220
TOC, mg/l	180	185	185	180	175	180	185	170
$S^=$, mg/l	41	65	67	76	66	68	69	73
SO_4, mg/l	85	75	80	80	80	78	72	65

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.6	7.6	7.4	7.6	7.6	7.5
ORP, mv	-370	-400	-410	-380	-420	-420
Temp., °C	23	22	21	23	23	22
COD_T/COD_F, mg/l	435/310	460/325	495/335	455/325	475/340	490/345
VA, mg/l as HAc	145	145	155	155	140	160
TOC, mg/l	155	165	170	155	155	160
$S^=$, mg/l	47	50	50	39	41	44
SO_4, mg/l	95	90	95	88	85	80

ANAEROBIC BASIN PROFILES (continued)

IV. 4 a.m. on 11/18/70

Deep Lagoon

Parameter	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.0	7.0	7.0	7.15	7.0	6.9	7.0	7.15
ORP, mv	-330	-350	-355	-365	-340	-350	-350	-360
Temp., °C	20	21	21	21	19	21	21	21
COD_T/COD_F, mg/l	890/775	920/760	910/725	820/695	900/765	890/760	880/730	810/715
VA, mg/l as HAc	218	276	276	240	264	240	264	240
TOC, mg/l	235	235	220	195	220	210	210	135
$S^=$, mg/l	40	42	38	49	35	35	38	50
SO_4, mg/l	170	180	180	105	160	160	160	80

Shallow Lagoon

Parameter	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.0	7.1	7.3	7.1	7.1	7.3
ORP, mv	-350	-360	-390	-350	-360	-380
Temp., °C	17	17	18	18	18	17
COD_T/COD_F, mg/l	790/670	790/660	760/585	835/700	805/700	760/600
VA, mg/l as HAc	205	192	192	205	205	205
TOC, mg/l	200	200	185	210	190	200
$S^=$, mg/l	30	31	45	29	31	42
SO_4, mg/l	185	185	125	165	160	110

ANAEROBIC BASIN PROFILES (continued)

IV. 4 p.m. on 11/18/70

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.0	7.0	7.1	7.0	7.0	7.0	7.1	7.3
ORP, mv	-350	-355	-360	-370	-355	-365	-370	-380
Temp., °C	23	23	22	21	23	23	22	21
COD_T/COD_F, mg/l	740/645	845/620	810/655	735/565	855/645	835/665	840/645	765/560
VA, mg/l as HAc	224	288	288	256	260	276	265	252
TOC, mg/l	225	235	220	205	240	230	235	220
$S^=$, mg/l	43	43	45	50	38	38	45	50
SO_4, mg/l	190	165	165	100	165	170	170	100

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.2	7.2	7.2	7.2	7.2	7.2
ORP, mv	-330	-345	-355	-340	-350	-355
Temp., °C	20	20.5	19	21	20	19
COD_T/COD_F, mg/l	745/495	740/515	725/445	755/520	750/530	730/465
VA, mg/l as HAc	180	204	192	228	228	204
TOC, mg/l	195	200	190	205	210	200
$S^=$, mg/l	27	31	47	25	36	45
SO_4, mg/l	110	190	110	110	150	115

ANAEROBIC BASIN PROFILES (continued)

V. 4 a.m. on 1/13/71

Parameter	Deep Lagoon							
	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.9	6.9	6.8	7.2	6.9	6.9	6.8	7.2
ORP, mv	-265	-230	-230	-250	-190	-230	-255	-285
Temp., °C	21	21	16	15	21	21	16.5	15
COD_T/COD_F, mg/l	775/735	785/735	785/720	725/645	780/760	790/765	785/710	725/630
VA, mg/l as HAc	240	240	216	216	240	240	228	192
TOC, mg/l	245	245	250	245	220	210	205	225
$S^=$, mg/l	17	24	21	42	17	22	23	42
SO_4, mg/l	230	215	230	96	245	245	225	45

Parameter	Shallow Lagoon					
	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	6.8	6.7	7.1	6.9	6.8	7.1
ORP, mv	-205	-220	-260	-210	-215	-255
Temp., °C	20	19	14	20	19	14
COD_T/COD_F, mg/l	755/700	745/700	680/590	760/700	755/700	675/600
VA, mg/l as HAc	252	240	228	240	228	216
TOC, mg/l	210	225	220	180	250	245
$S^=$, mg/l	Nil	5	10	Nil	5	5
SO_4, mg/l	300	310	164	300	410	145

ANAEROBIC BASIN PROFILES (continued)

V. 4 p.m. on 1/13/71

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.9	6.9	6.9	7.2	7.0	6.9	7.0	7.2
ORP, mv	-275	-275	-285	-305	-240	-255	-275	-285
Temp., °C	22.5	22	16	15	22	21.5	16	15
COD_T/COD_F, mg/l	780/605	765/600	775/675	680/590	785/610	765/605	740/535	665/515
VA, mg/l as HAc	228	216	240	228	228	240	228	216
TOC, mg/l	225	220	220	205	225	220	215	200
$S^=$, mg/l	21	30	33	67	31	31	18	40
SO_4, mg/l	230	220	245	75	225	210	220	100

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	6.9	6.9	7.0	6.9	6.9	7.1
ORP, mv	-245	-255	-280	-270	-260	-265
Temp., °C	22	19	14	22	20	15
COD_T/COD_F, mg/l	700/515	600/550	645/470	690/500	695/540	650/455
VA, mg/l as HAc	240	228	216	228	228	216
TOC, mg/l	190	175	165	185	190	180
$S^=$, mg/l	18	5	11	5	15	17
SO_4, mg/l	260	300	290	280	280	210

ANAEROBIC BASIN PROFILES (continued)

VI. 4:30 a.m. on 2/17/71

Parameter	Deep Lagoon							
	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.9
ORP, mv	-310	-300	-340	-340	-310	-320	-330	-340
Temp., °C	22	21	20	20	21	21	20	19
COD_T/COD_F, mg/l	740/645	740/680	725/655	715/630	740/670	740/645	705/645	695/585
VA, mg/l as HAc	230	230	240	192	230	278	336	264
TOC, mg/l	180	170	160	195	170	210	200	205
S=, mg/l	19	17	19	32	19	16	15	31
SO_4, mg/l	335	355	350	275	335	360	350	280

Parameter	Shallow Lagoon					
	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.0	6.9	6.9	7.0	7.0	7.0
ORP, mv	-320	-300	-280	-280	-300	-320
Temp., °C	20	21	21	21	21	20
COD_T/COD_F, mg/l	645/630	680/630	655/630	690/600	665/610	690/530
VA, mg/l as HAc	288	264	230	216	230	264
TOC, mg/l	185	205	210	195	195	180
S=, mg/l	5	5	5	5	8	19
SO_4, mg/l	370	370	365	360	325	330

ANAEROBIC BASIN PROFILES (continued)

VII. 4:30 a.m. on 3/17/71

Deep Lagoon

Parameter	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.8	6.8	6.8	6.7	6.8	6.8	6.8	7.0
ORP, mv	-340	-350	-350	-350	-330	-350	-350	-370
Temp., °C	24	25	25	25	24	25	25	24
COD_T/COD_F, mg/l	610/495	672/495	610/520	595/390	640/465	670/515	620/545	740/565
VA, mg/l as HAc	348	276	312	324	288	264	276	276
TOC, mg/l	165	170	160	160	170	175	170	190
$S^=$, mg/l	42	40	43	42	42	41	39	39
SO_4, mg/l	375	360	380	355	375	375	375	365

Shallow Lagoon

Parameter	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.0	7.0	6.9	7.0	7.0	7.0
ORP, mv	-300	-320	-340	-330	-345	-350
Temp., °C	22	23	22.5	22	23	23
COD_T/COD_F, mg/l	605/445	555/430	555/360	550/415	575/395	390/420
VA, mg/l as HAc	264	264	276	336	312	384
TOC, mg/l	155	145	150	160	160	165
$S^=$, mg/l	35	35	35	33	28	26
SO_4, mg/l	345	340	330	315	350	355

ANAEROBIC BASIN PROFILES (continued)

VII. 4:00 p.m. on 3/17/71

Deep Lagoon

Parameter	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.1	7.1	7.0	7.2	7.0	6.9	6.8	6.9
ORP, mv	-340	-360	-360	-380	-340	-350	-370	-370
Temp., °C	25	24	23	23	24	23	23	22
COD_T/COD_F, mg/l	600/545	630/560	655/570	590/500	620/545	610/570	655/530	545/450
VA, mg/l as HAc	228	228	252	156	240	252	276	276
TOC, mg/l	155	160	160	165	160	165	165	155
S=, mg/l	36	38	40	84	33	38	40	83
SO_4, mg/l	375	365	355	185	365	365	360	190

Shallow Lagoon

Parameter	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.3	7.2	7.1	7.2	7.2	7.1
ORP, mv	-320	-360	-360	-320	-350	-370
Temp., °C	24	23	22	23	23	23
COD_T/COD_F, mg/l	580/440	520/415	585/445	505/420	505/415	555/445
VA, mg/l as HAc	228	252	312	300	336	324
TOC, mg/l	155	145	155	145	145	155
S=, mg/l	30	29	33	33	32	29
SO_4, mg/l	345	335	325	325	330	330

ANAEROBIC BASIN PROFILES (continued)

VIII. 5:30 a.m. on 4/26/71

Deep Lagoon

Parameter	Inlet				Outlet			
	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	6.9	6.8	7.0	6.7	6.8	6.9	6.9	6.9
ORP, mv	-360	-350	-390	-390	-290	-360	-360	-380
Temp., °C	26	26	26	25	26	26	25	24.5
COD_T/COD_F, mg/l	1140/935	1170/880	1190/925	1290/760	1120/950	1090/925	1175/835	--
VA, mg/l as HAc	360	360	372	336	384	372	360	--
TOC, mg/l		Analyzers were not working						
S=, mg/l	119	111	115	130	111	116	114	--
SO_4, mg/l	100	105	65	40	90	85	75	--

Shallow Lagoon

Parameter	Inlet			Outlet		
	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.0	7.0	6.9	6.9	7.0	7.0
ORP, mv	-320	-340	-350	-320	-350	-360
Temp., °C	25	25	25	25	25	25
COD_T/COD_F, mg/l	915/830	830/820	1170/775	920/790	965/785	1050/940
VA, mg/l as HAc	418	480	420	456	480	420
TOC, mg/l		Analyzers were not working				
S=, mg/l	56	51	55	49	48	51
SO_4, mg/l	175	170	155	165	165	190

ANAEROBIC BASIN PROFILES (continued)

VIII. 4:00 p.m. on 4/26/71

	Deep Lagoon							
	Inlet				Outlet			
Parameter	Surface	3 ft	6 ft	Sludge	Surface	3 ft	6 ft	Sludge
pH	7.4	7.2	7.1	7.0	7.3	7.0	7.1	6.9
ORP, mv	-380	-390	<390	-400	-380	-380	-390	-390
Temp., °C	27	25	24	23	27	25	24	23
COD_T/COD_F, mg/l	1110/840	1150/910	1150/840	885/680	1000/950	1080/990	1060/955	885/730
VA, mg/l as HAc	312	336	312	240	384	324	348	288
TOC, mg/l		Analyzers were not working						
$S^=$, mg/l	83	102	107	138	105	117	148	148
SO_4, mg/l	120	110	55	50	105	95	25	25

	Shallow Lagoon					
	Inlet			Outlet		
Parameter	Surface	3 ft	Sludge	Surface	3 ft	Sludge
pH	7.4	7.3	7.3	7.3	7.3	7.3
ORP, mv	-320	-340	-370	-360	-370	-380
Temp., °C	27	25	24	27	24	23
COD_T/COD_F, mg/l	870/820	845/740	845/770	910/695	865/845	915/645
VA, mg/l as HAc	384	360	418	348	360	360
TOC, mg/l		Analyzers were not working				
$S^=$, mg/l	47	70	72	54	65	72
SO_4, mg/l	165	150	135	195	170	150

APPENDIX II

EXPERIMENTAL METHODS AND APPARATUS

I. Analytical Methods

The analytical methods used during the bench-, semi-pilot, and pilot-scale studies are:

A. **Alkalinity** - Alkalinity was determined to the methyl orange endpoint as given in Standard Methods (21).

B. Anaerobic Gas Composition - Gas composition was measured using a Perkin Elmer Model 154 Vapor Fractionator* (gas chromatograph).

C. Biochemical Oxygen Demand (BOD) - All five-day BOD determinations were performed in accordance with Standard Methods (21). In many cases analyses were made on both filtered and unfiltered samples. Filtered BOD tests were made on samples after filtration through quantitative filter paper (Whatman No. 42 or equivalent).

Twenty-day BOD determinations were based in part on a technique used at Office of Water Programs - Wheeling and in part on techniques developed by Union Carbide. Based on advice of the EPA the dilution water for all long-term BOD determinations was aerated to 15 to 20 mg/l dissolved oxygen with pure oxygen. Contained oxygen was monitored at frequent intervals (3, 5, 7, 10, 15 and 20 days) using a polarographic technique. Acclimated, petrochemical seed was used in all BOD determinations.

During initial BOD_{20} determinations problems were experienced with a high oxygen uptake after a period of 10 to 15 days. As the BOD within the samples was usually exerted prior to this time the increase in uptake by the blank resulted in a decrease in calculated BOD. In cases where the BOD was noted to decrease after 10 days' incubation the ultimate BOD was taken to be the maximum BOD observed within the 20-day test. The problem was ultimately avoided through a change in dilution water source and use of larger sample sizes for analysis.

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* Perkin Elmer, Norwalk, Connecticut

D. Chemical Oxygen Demand (COD - COD determinations were made on both unfiltered and filtered samples by the dichromate-reflux method as presented in Standard Methods (21). Special care was necessary during the analysis to contain the oxygen-demanding dissolved sulfides in the anaerobic samples. The sample was added to the reflux flask after all reagents were present so that the sulfides were oxidized by the dichromate before being evolved to the atmosphere in the acid environment.

E. Dissolved Oxygen (DO) - DO was measured using a polarographic probe* or by the alkaline-azide modification of the Winkler titration as presented in Standard Methods (21). The polarographic probe was calibrated using the Winkler Technique.

F. Gas-Liquid Chromatography - Specific chemical analyses were made by direct liquid injection using a Varian Aerograph Model 1200** chromatograph and a 10-foot Porapak Q column.

G. Nitrates - Evaluation of available methods on anaerobic-lagoon samples indicated the Brucine Method as outlined in Standard Methods (21) could be used. Other methods failed due to interferences.

H. Oxidation Reduction Potential (ORP) - ORP was measured using an Analytical Measurement Model 707M Redox-pH meter*** and a platinum probe.

I. pH - pH was measured using the Glass Electrode Method specified in Standard Methods (21).

J. Phosphate - An evaluation was made of the available phosphate methods to determine which was applicable to the anaerobic-lagoon system. The molybdenum-blue methods as outlined in Standard Methods (21) and the FWPCA Manual (22) were found to be unsuitable for the samples taken from the anaerobic lagoons. It was known that the presence of sulfide ions would interfere with the molybdenum-blue methods. However, after employing several sulfide-removal techniques (sparging under acidic conditions, mild oxidation, and precipitation) problems still existed with the above methods. Applying these methods after the removal of the sulfide led to the formation of a yellow solution upon the addition of the reducing agent. The yellow color could not be correlated to the phosphate content, and the blue complex would not form on standing for periods up to two hours. All the above methods employ sulfuric acid. Substituting hydrochloric acid for sulfuric acid eliminated the yellow-color formation and the blue complex formed as would be expected. Because the methods employing sulfuric acid performed well on synthetic samples but not well on actual samples, it might be concluded that the sulfuric acid reacted with some component in the samples under reducing conditions, whereas hydrochloric acid did not. Due to time consideration, the exact nature of this interference was not established.

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* Yellow Springs Instrument Company, Model No. 51 or 54, Yellow Springs, Ohio

** Varian Aerograph, Walnut Creek, California

*** Analytical Measurements, Inc., Chatham, New Jersey

Sparging with nitrogen under acidic conditions was found to remove the sulfide content to a satisfactory level to allow the application of the following molybdenum-blue method utilizing hydrochloric acid for the determination of soluble orthophosphate. A hydrolyzable phosphate was subjected to the soluble-orthophosphate method and found not to interfere with the orthophosphate analysis. After it was established that the hydrochloric acid version worked satisfactorily on synthetic samples, the method was applied to representative lagoon samples and spiked lagoon samples. The spikes were recovered and the orthophosphate content was found to check within approximately 2 milligrams per liter in the 0 to 50 milligrams per liter range.

A technique to permit the determination of all phosphorous-containing components was sought with no immediate success. With all the digestion techniques tried, part of the orthophosphate content known to be present was lost before the organic matter was completely digested. Because the phosphate employed by the bacteria is generally converted to a hydrolyzable phosphate, the total phosphorous method was abandoned for a method which would yield total-ortho-plus-hydrolyzable phosphate. The total-ortho-plus-hydrolyzable-phosphate method used was checked on known synthetic and representative samples and found to reproduce results within 5 milligrams per liter at the 50 to 100 milligrams per liter range (expected range on lagoon-effluent samples). It should be noted that the soluble-orthophosphate method utilizes a filtered sample, whereas the total-ortho-plus-hydrolyzable-phosphate method utilizes an unfiltered sample.

Preservation of samples was checked employing two different preserving agents: mercuric chloride and chloroform. No detectable difference was noted with respect to choice of preserving agent. However, because samples must either be sparged free of sulfide prior to the addition of mercuric chloride or have excess mercuric chloride added to remove the sulfide in a mercuric sulfide precipitate, it is recommended that the samples be preserved with chloroform (5 milliliters per liter).

1. Soluble Orthophosphate

a. Reagents

i) Sodium Molybdate Reagent: Dissolve 100 grams of sodium molybdate dihydrate ($NaMoO_4 \cdot 2H_2O$) in distilled water and dilute to one liter.

ii) Ascorbic Acid Reagent: Dissolve 10 grams of ascorbic acid in distilled water and dilute to 100 milliliters.

iii) Hydrochloric Acid Solution: Add 100 milliliters of concentrated c.p. hydrochloric acid to 500 milliliters of distilled water, cool, and dilute to one liter. Be careful.

iv) Phenolphthalein Indicator: Dissolve 0.5 gram of phenolphthalein disodium salt in distilled water and dilute to one liter.

v) Potassium Hydroxide Solution: Dissolve 6.5 grams of potassium hydroxide in distilled water and dilute to 100 milliliters.

b. Procedure

i) Filter 60 milliliters of a well-mixed sample through Whatman No. 4 paper, employing gravity filtration.

ii) Pipet 50 milliliters of the filtrate, or a suitable dilution, into a 100-milliliter, glass-stoppered graduated cylinder. The 50 milliliters of filtrate should not contain more than 0.6 milligram of phosphate (PO_4). Most samples will probably require a 1 to 10 dilution.

iii) Add four drops of phenolphthalein indicator and adjust the pH to the phenolphthalein endpoint with the hydrochloric acid or potassium hydroxide solution.

iv) Pipet 50 milliliters of distilled water into a 100-milliliter graduate and adjust the pH to the phenolphthalein endpoint. This will serve as a blank.

v) Using a pipet introduce 10 milliliters of the diluted hydrochloric acid solution dropwise into the sample graduate while sparging with nitrogen. Continue the nitrogen sparge for 10 minutes after the addition of hydrochloric acid. Add 10 milliliters of the hydrochloric acid solution to the blank; the nitrogen sparge is not necessary for the blank.

vi) Using a pipet, transfer 10 milliliters of sodium molybdate reagent to both sample and blank graduates and invert several times.

vii) Pipet one milliliter of ascorbic acid solution into the sample and blank graduates and invert several times.

viii) Dilute both sample and blank to 100 milliliters, invert several times, and allow to stand for 10 minutes, timed from the addition of ascorbic acid.

ix) Employing one-centimeter cells, measure the absorbance at 800 millimicrons with a Beckman* Model B or equivalent instrument. Use the blank to zero the instrument. From a previously prepared calibration curve read the concentration of soluble orthophosphate in milligrams per liter.

2. Total Hydrolyzable and Orthophosphate

a. Reagents

i) Concentrated Potassium Hydroxide Solution: Dissolve 65 grams of potassium hydroxide in distilled water and dilute to 100 milliliters. This solution must be stored in a polyethylene bottle.

ii) Concentrated Hydrochloric Acid: Concentrated c.p. hydrochloric acid (approximately 11.6 N).

iii) Remaining Reagents: The same as for soluble-orthophosphate method.

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* Beckman Instruments, Inc., Fullerton, California.

b. Procedure

i) Via a graduated cylinder, add 50 milliliters of a well-mixed sample, or suitable dilution to a 250-milliliter polyethylene bottle. The 50 milliliters of sample should not contain more than 0.6 milligram of phosphate (PO_4). Most samples will probably require a 1 to 20 dilution.

ii) Add 50 milliliters of distilled water to a 250-milliliter polyethylene bottle for use as a blank.

iii) Into both sample and blank pipet 10 milliliters of dilute hydrochloric acid dropwise while sparging with nitrogen. Continue the nitrogen sparge for 10 minutes after the addition of the acid. Sparging of the blank is not necessary.

iv) Into both sample and blank pipet 2 milliliters of concentrated hydrochloric acid and heat in a steam bath for 30 minutes.

v) Cool and filter through Whatman No. 4 paper into a 100-milliliter glass-stoppered graduate, washing the polyethylene bottle and filter paper with 5 milliliters of distilled water.

vi) Sparge again with nitrogen for an additional period of five minutes.

vii) Add four drops of phenolphthalein indicator and neutralize to the phenolphthalein endpoint employing the concentrated potassium hydroxide solution.

viii) Pipet 10 milliliters of the dilute hydrochloric acid solution into each graduate and invert several times.

ix) Continue with steps vi through ix of the soluble-orthophosphate method. From the calibration curve read the total-ortho-plus-hydrolyzable-phosphate content as PO_4 in milligrams per liter.

3. Calibration for Phosphate Methods

a. Calibration Solutions

i) Stock Phosphate Solution: Dissolve 0.7165 gram of anhydrous potassium dihydrogen phosphate (KH_2PO_4) in distilled water and dilute to one liter with additional water.

ii) Standard Phosphate Solution: Dilute 100 milliliters of the stock phosphate solution to one liter using distilled water.

iii) Test Phosphate Solutions: Dilute 2-, 4-, 8-, and 12-milliliter portions of the standard phosphate solution to 100 milliliters with distilled water. These test solutions will contain 1-, 2-, 4-, and 6-milligrams per liter phosphate, respectively.

b. Procedure

i) Obtain the absorbance of the above test phosphate solutions by following the procedure (Section I-b) described in the soluble-ortho-phosphate method, eliminating the nitrogen sparge.

ii) Plot the absorbance at 800 millimicrons vs milligrams per liter phosphate (PO_4).

L. Sulfate - Sulfate concentrations were measured using the Turbidimetric Method presented in Standard Methods (21). The analysis was investigated and no interferences were found in the anaerobic system.

M. Sulfide - Methods were developed for accurate determinations of both total and soluble ionic sulfide concentrations in the anaerobic-lagoon system. The methods are itemized below:

1. Total Sulfides

a. Purpose and Limitations - This method is designed for the determination of both soluble and insoluble ionic sulfide concentrations. By employment of this method and the method for soluble sulfide concentration, it is possible to calculate the insoluble sulfide concentration. The insoluble sulfide is generally regarded as the sulfide of heavy metals.

b. Principle - The sulfides are isolated by the addition of hydrochloric acid to the sample. The acid converts all the sulfides to hydrogen sulfide which is driven from solution by heating and a nitrogen purge. The hydrogen sulfide gas is then bubbled into a solution of zinc acetate and precipitated as zinc sulfide. The zinc sulfide precipitate is isolated, washed, and treated with a known amount of acidic silver nitrate solution, which yields a silver sulfide precipitate. By determination of the concentration of unreacted silver ion with chloride ion, it is possible to calculate the concentration of total ionic sulfide in the sample. The following reactions are utilized in this method:

$$S^{2-} + 2H^{+} \longrightarrow H_2S$$

$$H_2S + Zn^{++} + 2OAc^{-} \longrightarrow \underline{ZnS} + 2HOAc$$

$$ZnS + \text{(excess)}, Ag^{+}\ NO_3^{-} \xrightarrow[\text{Acidic}]{} Ag_2S + Zn(NO_3)_2 + AgNO_3$$

$$Ag^{+} + Cl^{-} \longrightarrow AgCl$$

c. Reagents and Apparatus

i) Zinc Acetate Reagent: Dissolve 22 grams of $Zn(OAc)_2 \cdot 2H_2O$ in 100 milliliters of distilled water.

ii) Sodium Hydroxide Solution: Dissolve four grams of NaOH in 100 milliliters of distilled water.

iii) Silver Nitrate Solution 0.01 N Ag /0.1 N HNO_3: To 500 milliliters of distilled water add 6.25 milliliters of c.p. HNO_3; after cooling this solution, add 1.698 grams of $AgNO_3$ and bring the volume to one liter with distilled water.* Take care.

iv) Hydrochloric Acid, Dilute Solution: To 500 milliliters of distilled water, add 250 milliliters of c.p. hydrochloric acid and then bring to a volume of one liter with distilled water.

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* Standardize the silver nitrate solution potentiometrically by titrating 25 milliliters of the solution in 100 milliliters of distilled water using 0.01 N HCl.

v) Hydrochloric Acid: Standard 0.01 N aqueous solution.

vi) pH Meter: Beckman Zeromatic* or its equivalent.

vii) Electrode System - Reference Electrode: Double-junction-sleeve type, Beckman* Part No. 40452; Indicator Electrode: silver billet, Beckman* Part No. 39261 - or equivalent.

d. Procedure

i) Set up the hydrogen sulfide generator as shown in the attached Figure 41. Purge the system with nitrogen (200 to 300 cubic centimeters per minute) through inlets A and B with the final purge through inlet B.

ii) Introduce 100 milliliters of dilute hydrochloric acid in the addition funnel with the addition funnel's stopcock closed.

iii) Remove the condenser and add the sample (c); the system should still be under a nitrogen purge. Replace the condenser and attach the delivery tube as shown in Figure 40.

iv) Immerse the delivery tube to within approximately one centimeter of the bottom of the collection vessel. The collection vessel is a 100-milliliter glass-stoppered graduated cylinder containing one milliliter of zinc acetate solution and 74 milliliters of distilled water.

v) Open the stopcock on the addition funnel and simultaneously transfer the nitrogen pressure from inlet B to inlet A, thus introduce the dilute hydrochloric acid into the reaction vessel.

vi) Allow the system to remain in this configuration until the solution comes to a boil; then transfer the purge to inlet B, closing the addition funnel's stopcock.

vii) The generation should be allowed to proceed for a period of 30 minutes. The purge is then transferred back to inlet A for a period of five minutes.

viii) At this time the collection vessel is removed.

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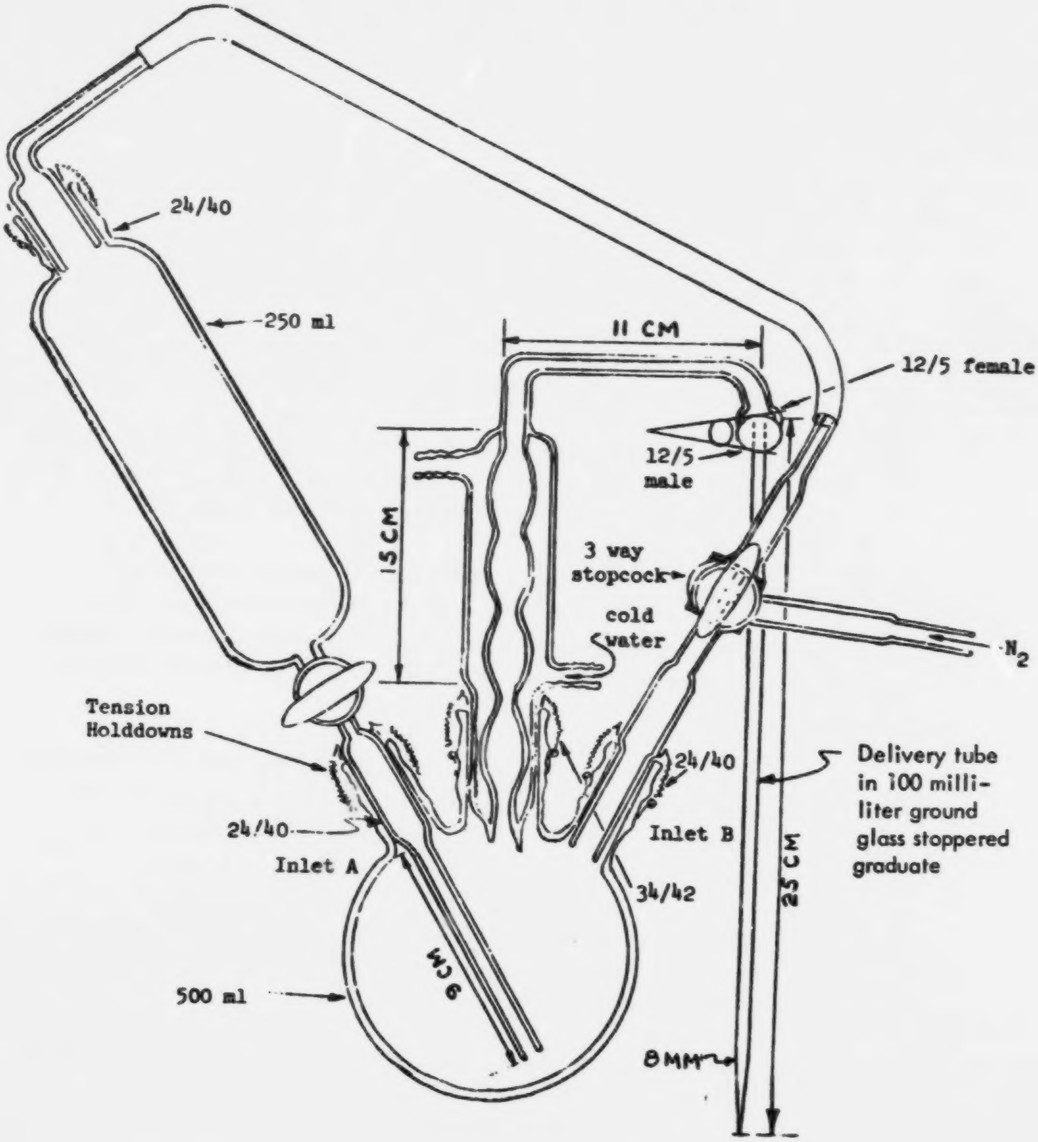
* Beckman Instruments Inc., Fullerton, California

FIGURE 40

HYDROGEN SULFIDE GENERATOR


24/40
250 ml
11 CM
12/5 female
12/5 male
15 CM
3 way stopcock
cold water
N_2
Tension Holddowns
24/40
24/40
Inlet B
Inlet A
34/42
Delivery tube in 100 milliliter ground glass stoppered graduate
23 CM
9 CM
500 ml
8 MM

ix) Add one milliliter of 1 N sodium hydroxide via a pipet to the collection vessel, bring the volume to 100 milliliters with distilled water and invert several times.

x) Allow the resulting precipitate to settle and remove the precipitate from solution by gravity filtration employing Whatman No. 4 filter paper.

xi) Wash the collection vessel with two 10-milliliter portions of distilled water, pouring the washings over the precipitate.

xii) Wash the precipitate with an additional 125 milliliters of distilled water, added by at least four additions.

xiii) Transfer the filter paper, containing the precipitate to a 200-milliliter electrolytic beaker. Next add 75 milliliters of distilled water to the beaker.

xiv) Stir the solution with a magnetic stirrer beating the filter paper into small pieces. To the solution containing the small pieces of paper, add 40 milliliters of 0.01 N silver nitrate solution by means of a buret with continuous stirring of the solution.

xv) Titrate the solution potentiometrically with 0.01 N hydrochloric acid. A typical titration curve is shown in Figure 41.

e. Calculation

$$\frac{(A\,N_{Ag} - B\,N_{HCl})\ 16030}{\text{sample volume (ml)}} = \frac{\text{milligrams } S^{2-}}{\text{liter}}$$

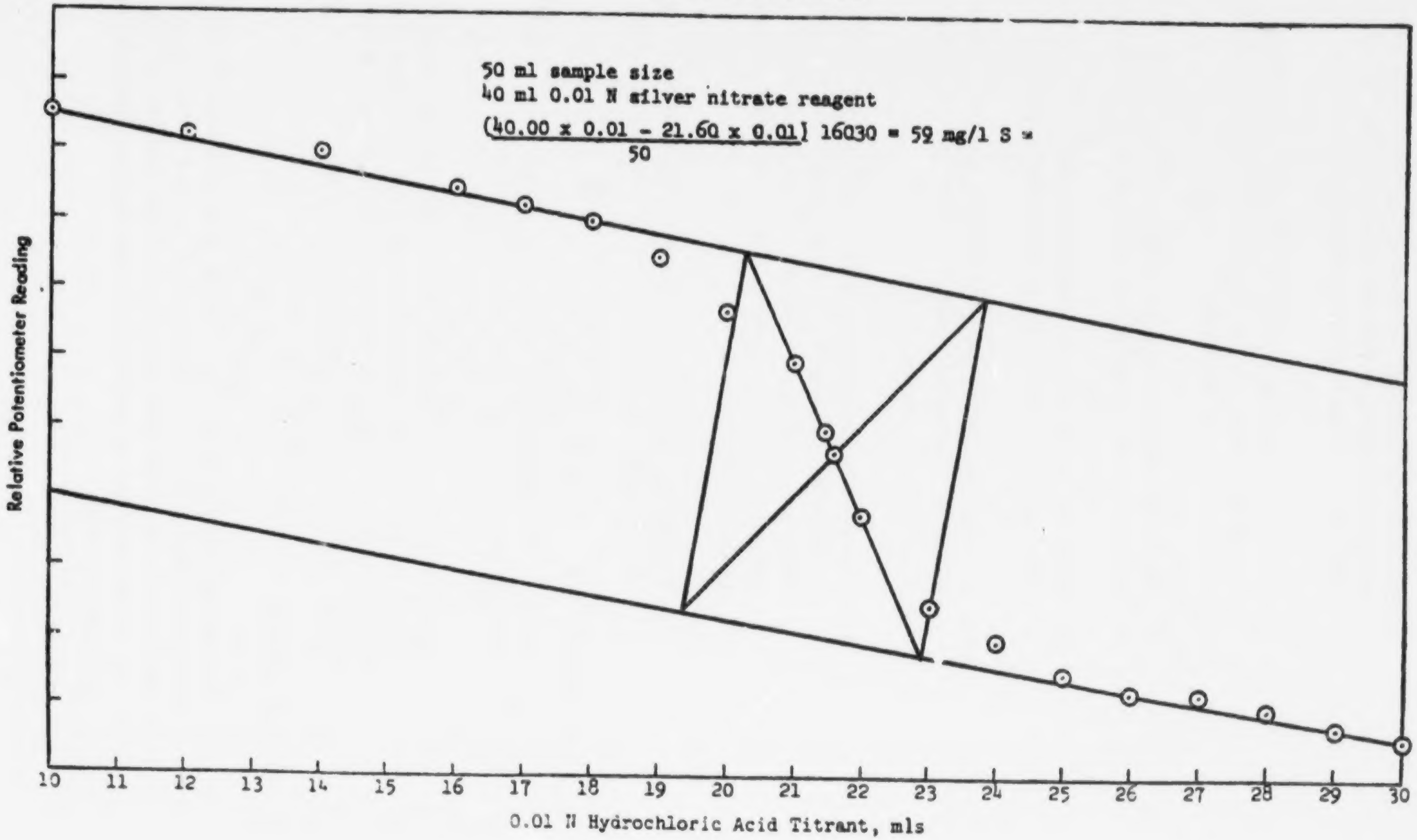
where A is the milliliters of 0.01 N silver nitrate, normally 40 as suggested in the above procedure; B is the milliliters of 0.01 N hydrochloric acid; N_{Ag} is the normality of silver nitrate; and N_{HCl} is the normality of hydrochloric acid.

2. Soluble Sulfides

a. Purpose and Limitations - This method is designed for the determination of ionic sulfides that are dissociated in a waste-stream sample. This method will not detect the insoluble sulfides (sulfides of heavy metals). The soluble sulfides are those which would cause most concern in an anaerobic system.

FIGURE 41

TITRATION CURVE



50 ml sample size

40 ml 0.01 N silver nitrate reagent

$$\frac{(40.00 \times 0.01 - 21.60 \times 0.01)}{50}\ 16030 = 59 \text{ mg/l S} =$$

b. Principle - The ionic sulfide is removed from other interfering ions in the waste-stream sample by precipitation of the sulfide as zinc sulfide, followed by a filtration of the precipitate. The precipitate is then treated with a known amount of acidic silver nitrate solution, which yields a silver sulfide precipitate. By determination of the unreacted silver ion via a potentiometric titration using standardized hydrochloric acid as the titrant, it is possible to calculate the concentration of soluble sulfide in the waste-stream sample. The following reactions are utilized in this method:

$$S^{2-} + Zn^{2+} \longrightarrow \underline{ZnS}$$

$$ZnS + \text{excess } Ag^{+} \longrightarrow \underline{Ag_2S} + Zn^{2+} + Ag^{+} \text{ (excess)}$$

$$Ag^{+} + Cl^{-} \xrightarrow{\text{acidic}} \underline{AgCl}$$

c. Reagents and Apparatus

i) Zinc Acetate Reagent: Dissolve 22 grams $Zn(OAc)_2 \cdot 2H_2O$ in 100 milliliters of distilled water.

ii) Sodium Hydroxide Solution, 1 N: Dissolve four grams NaOH in 100 milliliters of distilled water.

iii) Silver Nitrate Solution, 0.01 N Ag /0.1 N HNO_3: To 500 milliliters of distilled water add 6.25 milliliters of c.p. nitric acid; after cooling this solution, add 1.698 grams of $AgNO_3$ and bring the volume to one liter with distilled water.*

iv) Hydrochloric Acid, Standard 0.01 N Aqueous Solution:

v) pH Meter: Beckman Zeromatic**, or its equivalent.

vi) Electrode System - Reference Electrode: Double-junction-sleeve type, Beckman Part No. 40453; Indicator Electrode: silver billet, Beckman Part No. 39261 - or their equivalent.

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* Standardize the silver nitrate solution potentiometrically by titrating 25 milliliters of the solution in 100 milliliters of distilled water using standard 0.01 N HCl.

** Beckman Instruments Inc., Fullerton, California

d. Procedure

i) If the sample* contains solids, they should be removed by gravity filtration employing Whatman No. 4 paper.

ii) Pipet one milliliter of the zinc acetate solution into a 100-milliliter, glass-stoppered graduated cylinder.

iii) Introduce 25 ml to 50 ml** of sample to the graduated cylinder, bring the volume to 99 milliliters with distilled water and invert several times.

iv) Add one milliliter of 1 N sodium hydroxide via a pipet to the graduated cylinder and invert several times.

v) Allow the resulting precipitate to settle and remove the precipitate from the solution by gravity filtration employing Whatman No. 4 filter paper.

vi) Wash the cylinder with two 10-milliliter portions of distilled water, pouring the washings over the precipitate.

vii) Wash the precipitate with an additional 125 milliliters of distilled water added by at least four additions.

viii) Transfer the filter paper containing the precipitate to a 200-milliliter electrolytic beaker, followed by the addition of 75 milliliters of distilled water.

ix) Stir the solution with a magnetic stirrer breaking the filter paper into small pieces. To the solution containing the small pieces of paper, add 40 milliliters of 0.01 N silver nitrate solution by means of a buret, with continuous stirring of the solution.

x) Titrate the solution potentiometrically with 0.01 N hydrochloric acid. A typical titration curve is illustrated in Figure 41.

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* Samples should be stabilized at the time of sampling by adjusting the pH to approximately 11.5. Otherwise the sulfide may be oxidized and/or lost via volatile hydrogen sulfide prior to being analyzed.

** Sample size will be determined by the expected sulfide concentration and can best be determined employing the formula in the calculation.

e. Calculation

$$\frac{(A\,N_{Ag} - B\,N_{HCl})\ 16030}{\text{sample volume (ML)}} = \frac{\text{milligrams } S^{2-}}{\text{liter}}$$

where A is the milliliters of 0.01 N silver nitrate, normally 40 as suggested in the above procedure; B is the milliliters of 0.01 N hydrochloric acid; N_{Ag} is the normality of silver nitrate; and N_{HCl} is the normality of hydrochloric acid.

N. Suspended Solids (SS) and Volatile Suspended Solids (VSS) - Suspended-solids concentrations were measured using the technique given in Standard Methods (21) except that a glass-fiber filter was substituted as the filter media. Volatile-solids concentrations were determined by measuring the difference between solids concentration before and after ignition at 600°C.

O. Total Carbon (TC) and Total Organic Carbon (TOC) - TC and TOC measurements were made on filtered samples using the Union Carbide Total Carbon Analyzer.* Total carbon was measured directly on the filtered samples while TOC was measured after inorganic carbon compounds were removed from the filtered samples by acidification to a pH below 4.3 and sparging with nitrogen gas.

P. Volatile Acids (VA) - Volatile-acids concentrations were determined as specified in Standard Methods (21).

II. Experimental Apparatus

A. Anaerobic Filters

Bench-Scale Filters - Bench-scale submerged filters were fabricated from Plexiglas tubing with an inside diameter of 3.5 inches. They were about two feet long and packed with 1-inch Berl saddles, which provided void volume of about 3 liters, or 58 per cent. Both bench units were maintained at 35°C by electrical heating tape wound around each tube. Units were fed from a nitrogen-mixed feed container using a peristaltic pump. Effluent gas and liquid were separated in a 500-milliliter separatory funnel; the liquid was retained for analysis, while the product-gas flow was monitored in a wet test meter.

Semi-Pilot Filters - Semi-pilot scale filters were fabricated from 12-inch diameter stainless-steel tubes to provide six feet of packed bed height. Filters were packed with 1-inch diameter, hand-graded river gravel to provide a 41 per cent void volume of 14.2 gallons. Doughnut-shaped distribution rings were installed at 2-foot intervals to prevent short-circuiting along the wall. All three units were insulated and thermostatically controlled at 35°C by electrical heating tape wound about them.

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* Union Carbide Instruments Division, White Plains, N. Y. (now Ionics Inc., Cambridge, Mass.).

Petrochemical waste adjusted for pH and organic concentration and to which nutrients were added was fed by a peristaltic pump from 50-gallon, polyethylene-lined drums. Product gas was measured with wet test meters and analyzed for methane.

B. Contact Digesters

Bench-Scale Digesters - Bench scale contact digestion units consisted of five-gallon carboys which were back-mixed and continuously fed. An active volume of 16 liters was used. All units were mixed by recycling product gas with a diaphragm-type gas pump to a submerged tee in the bottom of the reactor. Tube-type and packed-bed clarifiers were tested as solids separation devices. Net product gas was analyzed, and flow was metered.

The tube-type clarifiers used in the bench-scale studies consisted of a multiplicity of 5-mm diameter tubes inside a 30-mm diameter tube inclined at an angle of approximately 45° with the horizontal. This type clarifier system exploits the theoretical advantages of low hydraulic flow per unit area of clarifier. The inclined tubes are self cleaning, the settled solids slide down the tubes back into the reactor or solids recycle system. Sludge was recycled with a peristaltic pump back through the feed line.

The packed-bed clarifiers were 1-inch O.D. by 12-inch long tubes packed with either pea-sized gravel or 6-mm diameter glass beads. Waste flow was directed upwards through the bed. The beds in these small units were back-flushed daily by simply raising them until the solids and effluent were flushed back to the reactor through the flexible connections used.

Semi-Pilot Digesters - The semi-pilot scale unit was a 5600-gallon below-grade, steel vessel having a bottom diameter of 9 feet, a top diameter of 12.5 feet, a liquid depth of 8 feet, and a removable steel cover. The waste was fed continuously with a peristaltic pump from a 3000-gallon tank containing feed adjusted to pH 7 and to which nutrients had been added. The digester contents were mixed hydraulically with a centrifugal pump. The digester was maintained at 35°C by means of internal coils using recycled hot water as the heat transferring agent. Solids were recovered from the effluent by use of an internal tube-type clarifier. This clarifier consisted of 49, two-inch diameter stainless steel tubes inclined at an angle of 60° with the horizontal. The liquor flowed upward through the tube to an overflow box and thence out of the digester through a gas-seal leg. Product gas was metered and analyzed.

C. Anaerobic Lagoons

Semi-Pilot Lagoons - Semi-pilot scale studies were made treating an actual petrochemical waste in anaerobic lagoons ranging in size from 50 gallons to 5500 gallons. With one exception, all units were cylindrical vessels of either polyethylene-lined steel or stainless steel construction, open-topped and located outdoors to take advantage of photosynthetic bacteria. The largest unit (5500 gallons) was a prismoid constructed of plywood having top dimensions of 24 by 18 feet and sides sloped at 45°. This latter unit is described in Figure 42. Submerged influent and effluent connections were used in all units. Gas was not collected in these units.

D. Demonstration Facility

The process consisted of the treatment of clarified, pH-adjusted wastewater in two anaerobic lagoons followed in series by aerated stabilization and by facultative lagoons for sludge separation and digestion.

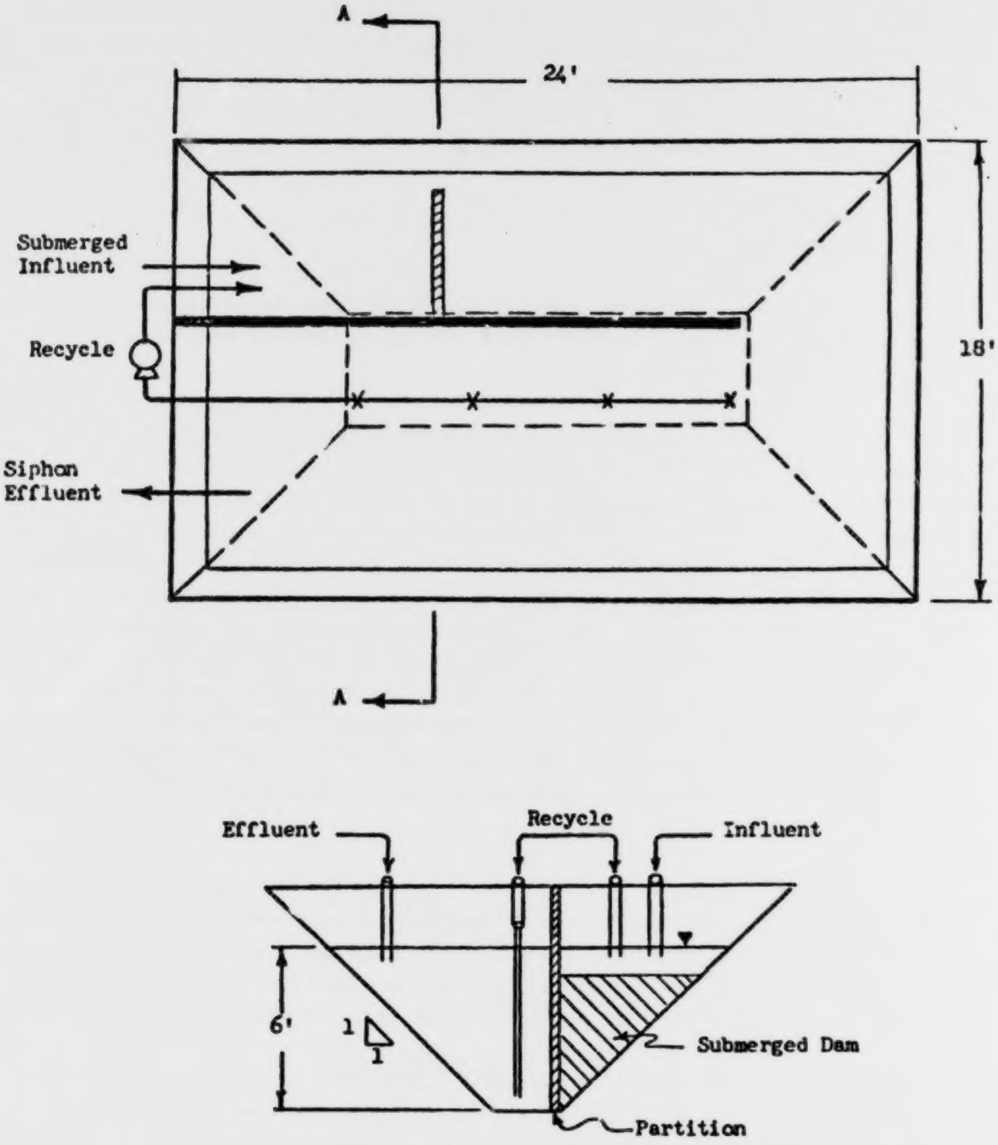
Influent Pretreatment - Clarified petrochemical wastewater from the Texas City Plant was mixed and pH adjusted in a 5600-gallon basin. Because the wastewater was usually alkaline provisions were made for only the controlled addition of sulfuric acid. Sulfuric acid was pumped from drums to a constant head tank, or stand pipe, to provide constant pressure to an automatically controlled motor valve. The excess acid overflowed the head tank and returned to the feed drum. The controlled sulfuric acid flow from the head tank flowed through the motor valve to the mixing tank. Dilute and at times concentrated wastewater plus metered flows of nutrients, ammonium hydroxide (25%) and phosphoric acid (75%), were pumped to the mixing basin. The contents of the basin were mixed hydraulically with a centrifugal pump. A portion of the recycle stream from this pump passed through a 2-celled pH analyzer with the output signal used to control the addition of sulfuric acid.

Anaerobic Lagoons - The rate of feed to the anaerobic lagoons was controlled by a steam-driven reciprocating pump. The pretreated wastewater was pumped to a surge chamber to dampen the pulsations and thence through a totalizing flowmeter. The total flow then passed through a weir-type flow splitter to split the total flow, one-third to the shallow lagoon and two-thirds to the deep lagoon.

These two lagoons were similar in area (50' x 100') but different in depth; one was six-feet deep, the other 12-feet deep. Upstream equipment was designed to provide flows equivalent from 8 to 15 days (or longer) residence time in the anaerobic lagoons. The lagoons were large in area to model more closely full scale with respect to wind and wave action and their effects on reaeration and on mixing. In order to

FIGURE 42

Anaerobic Pilot-Scale Reactor


A
24'
A
Submerged
Influent
Recycle
Siphon
Effluent
18'
A
Effluent
Recycle
Influent
6'
1
1
Submerged Dam
Partition

increase the similarity, free-board was low at one foot to allow good wind action. Straight vertical sides were used to obviate any effects of a difference in top and bottom surface area.

Because of the uncertainty on the relative effects of the anaerobic bottom and aerobic surface, combined with mixing and aeration, two lagoon depths, 6 and 12 feet, were used. The direction of placement was selected so that the dividing wall common to both lagoons extended in a north-south direction to ensure that both lagoons received equal periods of light from the sun. Another feature was that the direction of water flow was opposite to the prevailing southeasterly wind direction to reduce the opportunity for short circuiting by warmer water being blown across the upper portion of the lagoons to the outfall.

Inlets and outlets were simple tees located at the midpoint of opposite ends of the lagoons. More exotic distribution or collection systems were thought to be unnecessary since outlets in a full-scale lagoon likely would be no less than fifty feet apart due to distribution achieved by input velocity and wind action.

The influent wastewater flowed through submerged inlets through the lagoons to submerged, vented overflows. Since only a portion of the stream was to be treated aerobically, provisions were made to collect and dispose of the excess anaerobic lagoon overflow. Both lagoons overflowed to a sump. Connections to each or both lagoon-overflow lines were used to provide treated water for the aerated-stabilization feed pump. Excess anaerobic lagoon overflow was transferred from the sump by pumps to a disposal basin.

Aerated Stabilization - Anaerobically treated wastewater from either, or both, anaerobic lagoons was pumped at a controlled rate by a steam-driven reciprocating pump to a surge chamber for pulsation damping. The wastewater flowed from the surge chamber through a totalizing water meter to the aerated-stabilization unit for further organic reduction.

The aerated stabilization unit utilized a variable-speed Yoemans'* cone surface aerated and later a high speed Ashbrook aerator** installed in the 31,000-gallon basin (9 ft deep,7 ft square bottom, 30 ft square surface).

The effluent from the aerated-stabilization unit flowed by gravity to lagoons for solids separation and stabilization.

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* The Clow Co., Melrose Park, Ill.

** Ashbrook, Inc., Houston, Texas

Sludge Separation and Stabilization - Solids contained in the aerated-stabilization unit effluent were removed in the facultative lagoons by gravity settling. Two lagoons in series were used, each one provided two days' detention time with the aerated stabilization unit operating at a 3-day detention time. The primary function of these lagoons was solids removal as little or no removal of soluble COD or BOD_5 was expected. Lagoons were 13 ft wide by 26.5 ft long by 6 ft deep each.

Sampling - Provisions were made for collecting 24-hour composite samples of major streams. In order to ensure representative material the samples were held in ice-cooled containers to prevent degradation during the collection period.

1 *Accession Number* **W**	2 *Subject Field & Group* 05D	**SELECTED WATER RESOURCES ABSTRACTS** **INPUT TRANSACTION FORM**

5 *Organization*

Union Carbide Corporation, Chemicals and Plastics Operations Division, Research and Development Department, South Charleston, West Virginia

6 *Title*

ANAEROBIC TREATMENT OF SYNTHETIC ORGANIC WASTES

10 *Author(s)*

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16 *Project Designation*

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21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Chemical Wastes, *Industrial Wastes, *Anaerobic Digestion

25 *Identifiers (Starred First)*

*Anaerobic Lagoons, *Anaerobic Filter, *Contact Digester, Anaerobic-Aerobic Processes

27 *Abstract*

Bench, semi-pilot, and pilot scale studies of three anaerobic treatment processes have shown the anaerobic lagoon to be both the performance and the economic choice for pretreatment of petrochemical wastes in warm, spacious locations. Semi-pilot scale studies of anaerobic contact digesters and packed bed reactors indicated performance problems when treating actual petrochemical wastes. Experimental data from several sources were combined to prepare a design procedure for anaerobic lagoon pretreatment systems.

Operation of a large (30 gpm) pilot plant consisting of anaerobic lagoons followed by aerated stabilization and facultative ponds provided a BOD removal from the petrochemical wastes of greater than 90 percent and a resistance to both organic-loading and pH shocks. Comparison of an anaerobic-aerobic system with a strictly aerobic system pointed out an economic advantage with the series system due to lower sludge-disposal and oxygen requirements.

Abstractor Hovious, Joseph C.

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